ANNOUNCEMENT OF WEEKLY PUBLICATION

The past two years have witnessed the partial realization of a plan, long favored by officers of this Department and of the State Agricultural Experiment Stations, for centralized publication of some of the results of scientific research upon agricultural problems.

With the more general appreciation of the economic necessity for further researches in all sciences allied to agriculture and the recognition of the suitability of the Journal of Agricultural Research for recording new data of fundamental significance to agriculture, the papers awaiting publication in this Journal have increased to a degree that warrants more frequent issuance. Beginning with Volume V, therefore, a number of the Journal of Agricultural Research will appear each week.

D. F. HOUSTON,
Secretary of Agriculture

Washington, D. C.,
September 2, 1915

JOURNAL OF AGRICULTURAL RESEARCH

VOLUME V

OCTOBER 4, 1915—MARCH 27, 1916

DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE, WITH THE COOPERATION OF THE ASSOCIATION OF AMERICAN AGRICULTURAL COLLEGES AND EXPERIMENT STATIONS

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All correspondence regarding articles from Experiment Stations should be addressed to Raymond Pearl, Journal of Agricultural Research, Orono, Maine.

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ERRATA

Page 20, last line, "ammonium sulphate" should read "ammonium carbonate."

Page 22, legend under figure 16 should read "Diagram showing the number of corn plants up and dry matter produced in 21 days on College loam with sodium sulphate, sodium carbonate, and sodium chlorid," etc.

Page 23, legend under figure 18 should read "Diagram showing the number of wheat plants up and dry matter produced in 16 days on Greenville loam with ammonium carbonate, sodium carbonate, and potassium carbonate," etc.

Page 59, "*Dipsacus follonum*" should read "*Dipsacus fullonum*."

Page 63, "*Capsula bursa pastoris*" should read "*Capsella bursa pastoris*."

Pages 65, 66, 67, "*Helianthus diversicatus*" should read "*Helianthus divaricatus*."

Page 174, line 17 from bottom, "32°" should read "30°."

Page 175, Table II, last column, last line, "60.0" should read "67.0."

Page 189, line 13 from bottom, "form" should read "from."

Page 191, line 17 from bottom, "Fusarium Wollenw." should read "Fusarium hyperoxysporum Wollenw."

Page 210, Plate XVII, "figure 1" should read "figure 4," "figures 2, 3, 4" should read "figures 1, 2, 3."

Page 271, line 22, "weight of the kernels" should read "weight of the extracted kernels."

Page 272, line 8, "It was normal" should read "It was not normal."

Page 279, footnote b, "Rabbit 651" should read "Rabbit 951."

Page 291, "*Panax quinquefolia*" should read "*Panax quinquefolium*."

Page 334, line 11 from bottom should read "thermoelements in this section may be observed."

Page 694, line 7, "2 N 2/5" should read "N 2/5."

Page 700, line 14, "N/5" should read "N 2/5."

Page 752, footnote, line 2 from bottom, should read "For 100 c. c. synthetic solution take 1 c. c. of M/5 magnesium sulphate, 1 c. c. asparagin M/5, and 5 c. c. of each of the other solutions, and add to 88 c. c. water. Steam on three successive days."

Page 780, Plate LVI, figure 2, *B*, "0.1 per cent" should read "0.01 per cent."

Page 782, "*Pinus murrayana* Oreg. Com." should read "*Pinus contorta* Loud."

Page 911, line 13 from bottom should read "and a humid soil after the removal of lime and magnesia."

Page 912, line 10 from bottom should read "10 gm. of dry soil after the removal of lime and magnesia."

Plate LXVI, "Fig. 2" should read "Fig. 1."

Page 986, last line, "also" should read "next to."

Page 987, first footnote, "eighth" should read "seventh."

Page 1016, line 16, "comparing them" should read "comparable."

Page 1023, Table VII, first column, "12.15 a. m." should read "12.15 p. m."

Page 1036, line 4, "spore" should read "pore."

Page 1063, line 3, "4.0065 feet" should read "4.0056 feet."

Page 1071, figure 8 and tenth line from bottom of page, "$C=3.078L^{1.022}$" should read "$C=3.078L^{0.022}$."

Page 1073, line 17, "4.0058 feet" should read "4.0086 feet."

Page 1081, Table VIII, "4.0058-foot notch" should read "4.0086-foot notch."

Page 1083, bottom of page, "$H\left(2.5-\frac{0.0195}{S^{0.75}}\right)$" should read "$H^{\left(2.5-\frac{0.0195}{S^{0.75}}\right)}$."

Page 1095, Table XIV, under "Head, 1 foot," ninth column, tenth line, "4.52" should read "4.53."

Page 1112, Literature cited, "Forschheimer" should read "Forchheimer."

Page 1117, legend under figure 1, end of line 6, "spring" should read "fall."

Page 1187, "22.9" should read "12.9."

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JOURNAL OF AGRICULTURAL RESEARCH

DEPARTMENT OF AGRICULTURE

VOL. V WASHINGTON, D. C., OCTOBER 4, 1915 NO. 1

EFFECT OF ALKALI SALTS IN SOILS ON THE GERMINATION AND GROWTH OF CROPS

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Professor of Agronomy, Utah Agricultural Experiment Station

INTRODUCTION

In arid regions the soil is likely to contain an accumulation of soluble salts in such quantities that the growth of vegetation is hindered. Indeed, in many sections the type of vegetation is determined almost entirely by the alkali content of the soil. Every grade may be found, from the soil containing so much soluble salt that no vegetation whatever will grow to the soil containing scarcely sufficient soluble material for the needs of plants.

In the western part of the United States there are millions of acres of land of each alkali type. The worst of these lands need not be considered at present for agricultural purposes, but there are vast areas just on the border line. If everything is favorable, they produce profitable crops; but during the average year crops are a failure. If a permanent agriculture is to be established on these soils, it will be necessary to increase greatly our knowledge of methods of handling them.

A large part of the unsettled land of the West contains more or less alkali. Chemical analysis of the soil can easily be made and the alkali content determined; where the alkali content is very high, the land is not suited to agriculture; where it is low, the alkali can not be considered an interfering factor. It is the soil containing a medium amount that causes the difficulty. Many projects that were condemned when an analysis of the soil was made have proved later to be fertile agricultural tracts. On the other hand, lands whose salt content was thought to be sufficiently low for crop production have later been abandoned. There are not sufficient exact experimental data available to make it

[1] The author wishes to acknowledge his indebtedness to his assistants, Messrs. Howard J. Maughan, George Stewart, and A. F. Bracken, for their faithful and intelligent efforts in conducting certain parts of the work; to Mr. R. M. Madsen, Miss Alma Esplin, and Mr. N. I. Butt for their care in making many laborious computations; and to a number of other faithful assistants who helped in conducting the experiments.

possible in all cases to determine how well crops will grow in a soil of known alkali content.

In view of the great practical importance of the subject as well as its scientific interest, considerably more information should be gathered on the relation of alkali in soils to crops. The limits of endurance of each crop for each salt in the different kinds of soil should be fixed with much greater exactness.

It was in response to this need that the work reported in this article was undertaken.

REVIEW OF THE LITERATURE

The effect on plants of the salts classed as alkali has been the subject of much investigation, but the greater part of this work has been done in solution cultures rather than in the soil. By using water cultures an attempt has been made to limit the great number of factors that exist in the soil, where some of the salts are neutralized and others are absorbed. The work of Loew (16),[1] Kearney (12–14), Harter (7, 14), Cameron (5, 13), Breazeale (1–2, 5), Dorsey (6), Osterhout (20–21), True (26), McCool (18), and others in this country and numerous workers in Europe has added many facts to our knowledge of the action of single salts and balanced solutions on plants grown in water cultures. These workers have shown the great toxicity of salts like magnesium when used alone in a water culture and how this toxicity may be reduced by the presence of other elements.

The facts obtained in these experiments have increased our knowledge of plant physiology and the fundamental nature of alkali; but conclusions drawn from them should not be too definitely applied to the action of alkali as it is found in the soil.

For example, in solution cultures the salts of magnesium when present alone are very toxic, while if added to a normal soil they are no more toxic than a number of other salts. Again, Kearney and Cameron (13) concluded from their work with solutions that "the toxic effect of injurious salts is due very much more to the influence of the cathions (derived from the basic radicle) than to the anions (furnished by the acid radicle)." This may be true for solution cultures, but it certainly does not always hold for salts added to soils, as the results in the present paper will show.

It is desirable, therefore, in studying the effect of soil alkali on plants to use soil as a medium in which to grow the plants, even though it is somewhat difficult to watch all the factors involved.

In 1876 Toutphoeus (9), and Henri Vilmorin (9) about the same time, published results of experiments showing that chemical fertilizers when added to the soil in too large quantities inhibit the germination of seeds.

[1] Reference is made by number to "Literature cited," p. 52–53.

Nessler in 1877 (9) stated that 0.5 per cent of cooking salt (sodium chlorid) injured the germination of rape, clover, and hemp, and that wheat withstands this solution, but is injured by a 1 per cent solution.

Hilgard was a pioneer in the study of alkali soils and as early as 1877 began publishing results on his investigations in California. From that time to the present his contributions, together with those of Loughridge, his associate, have constantly enriched the literature. Their results are contained in numerous publications of the California Agricultural Experiment Station and were well summarized by Hilgard in 1906 (11).

An excellent review of the work done on alkali in the United States up to 1905 is also given by Dorsey (6). A large proportion of the work on alkali in this country has consisted of the analysis of soils for the determination of the presence of various alkali salts.

A number of workers, however, have investigated the amounts of the different salts necessary to inhibit crop growth. Hilgard (10) and Loughridge (17) made numerous studies of the alkali content of California soils and the limits of concentration of the various salts at which cultivated and native plants cease to grow.

Buffum (3), Slosson (23), and Knight and Slosson (15) in Wyoming carried on many experiments on the effect of alkali on the germination of seeds and growth of crops. From their results they concluded that there is a regular decrease in the germination of seeds as the osmotic pressure increases; and there is no apparent difference between sodium or potassium, or between the sulphate and chlorid of the same or different salts. It will be noted that this conclusion is not borne out by the data contained in the present paper.

Headden (8), working with sugar beets, found that varieties differed in their resistance to alkali. He also determined the effect of sodium carbonate, sodium sulphate, and magnesium sulphate on the germination of sugar-beet seed. He concluded that—

> The best seed germinated freely in soil containing as much as 0.10 per cent of sodium carbonate but the plants were attacked by as much as 0.05 per cent and it is doubtful whether any of them can survive when there is as much as 0.10 per cent of this salt present in the soil. Sodium sulphate affects the germination to a much less degree, even when it is equal to 0.90 per cent of the air-dried soil, but it is injurious when present in larger quantities. When both sodium carbonate and sodium sulphate are present in equal quantities, the action of the carbonate, or black alkali, is only slightly or not at all mitigated. Magnesium sulphate retards, but does not prevent germination when present in quantities equal to 1 per cent of the air-dried soil.

Stewart (25) made germination tests of a number of crops in soil to which different quantities of alkali salts had been added. He found sodium carbonate to be the most injurious of the alkalies with most crops. However, with white clover and red clover white alkali proved as injurious as the black. In their resistance to alkali the cereals stood in the following order: Barley, rye, wheat, and oats, barley being the most

resistant. He found that 0.50 per cent of either carbonate or chlorid was fatal to germination in almost all cases.

Hicks (9) found that—

> Muriate of potash and sodium nitrate used as fertilizers in strengths of 1 per cent or more are very detrimental to the germination of seeds, whether applied directly or mixed with the soil; that the chief injury to germination from chemical fertilizers is inflicted upon the young sprouts after they leave the seed coat and before they emerge from the soil, while the seeds themselves are injured only slightly or not at all.

Shaw (22) after a great many tests was led to the conclusion that wherever the chlorid content of soil approached 0.2 per cent beet culture was unsuccessful.

Kearney (12) listed crops most likely to succeed in alkali of various concentrations, as follows: Excessive alkali (above 1.5 per cent), native and foreign saltbush and salt grasses; very strong alkali (1.0 to 1.5 per cent), date palm and pomegranate bushes; strong alkali (0.8 to 1 per cent), sugar beets, western wheat-grass, awnless brome-grass, and tall meadow oat-grass; medium strong alkali (0.6 to 0.8 per cent), meadow fescue, Italian rye-grass, slender wheat-grass, foxtail millet, rape, kale, sorgo, and barley for hay; medium alkali (0.4 to 0.6 per cent), redtop, timothy, orchard grass, cotton, asparagus, wheat for hay, oats for hay, rye, and barley; weak alkali (0.0 to 0.4 per cent), wheat for grain, emmer for grain, oats for grain, kafir, milo, proso millet, alfalfa, field peas, vetches, horse beans, and sweet clover.

Miyake (19), working on the effect of the chlorids, nitrates, sulphates, and carbonates of sodium, calcium, magnesium, and potassium on rice, found that the antagonistic action of individual salts was in part overcome when the salts were combined.

PRELIMINARY STUDIES

RESULTS IN 1912

The study of soil alkali in its relation to the growth of plants was begun by the Utah Experiment Station in 1912. The first tests were made in glass tumblers which held about 200 gm. of soil. The soil used was loam from the Greenville (Utah) Experimental Farm. The chemical and physical analyses of this soil are given in Tables VIII and IX.

The crops were New Zealand wheat (*Triticum aestivum*) and sugar beets (*Beta vulgaris*), 10 seeds being planted in each glass. Each sugar-beet seed, or ball, contains more than one germ; hence, more plants were usually obtained than the number of seeds planted.

The salts were added from stock solutions and were thoroughly mixed with the soil two or three days before the seeds were planted, July 28. The sugar beets were harvested on August 5, and the wheat on August 10. The plants that had come up were counted and their height and dry weight determined. The results are given in Tables I, II, and III.

TABLE I.—*Percentage of germination of wheat and sugar beets in soil containing sodium chlorid, sodium carbonate, sodium sulphate, and magnesium sulphate in different concentrations. Salts added in solution*

Concentration of salts (p. p. m. of dry soil).	Percentage of germination.							
	Wheat.				Sugar beets.			
	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.
None	90	90	90	90	123	123	123	123
100	60	100	80	80	90	50	100	80
500	90	70	40	90	150	40	70	100
1,000	60	70	80	80	170	90	110	120
2,000	40	70	60	90	130	120	120	160
3,000	0	50	50	60	20	100	200	110
4,000	0	50	70	70	0	130	210	180
5,000	0	80	60	50	0	150	250	70
6,000	0	70	60	90	0	90	190	120
7,000	0	30	80	60	0	20	210	210
8,000	0	40	40	80	0	0	150	240
9,000	0	30	70	60	0	0	100	180
10,000	0	0	40	70	0	0	110	210

TABLE II.—*Average height (in centimeters) of wheat and sugar-beet plants raised in soil containing alkali salts in various concentrations*

Concentration of salts (p. p. m. of dry soil).	Average height of plants.							
	Wheat.				Sugar beets.			
	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.
None	24	24	24	24	7	7	7	7
100	24	24	27	25	7	7	7	7
500	24	24	26	21	7	7	7	7
1,000	17	23	26	27	7	7	7	7
2,000	8	23	27	25	3	7	7	7
3,000	....	22	23	27	3	7	7	5
4,000	....	22	19	25	....	6	6	5
5,000	....	22	21	25	....	6	6	6
6,000	....	20	19	26	....	4	6	6
7,000	....	10	12	22	....	3	5	7
8,000	....	4	10	22	....	....	6	5
9,000	....	3	5	23	....	....	4	5
10,000	....	....	7	26	....	....	4	5

TABLE III.—*Quantity of dry matter (in grams) produced by wheat and sugar-beet plants raised in soil containing alkali salts in various concentrations*

Concentration of salts (p. p. m. of dry soil).	Dry matter.							
	Wheat.				Sugar beets.			
	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.
None	0.131	0.131	0.131	0.131	0.020	0.020	0.020	0.020
100	.095	.142	.100	.118	.016	.101	.019	.013
500	.185	.082	.070	.117	.032	.007	.012	.017
1,000	.050	.110	.103	.147	.034	.015	.020	.018
2,000	.034	.117	.121	.114	.017	.023	.005	.027
3,000	....	.098	.075	.114	.005	.023	.033	.029
4,000	....	.080	.078	.108	....	.026	.039	.031
5,000	....	.119	.080	.073	....	.026	.048	.013
6,000	....	.090	.088	.144	....	.013	.035	.023
7,000	....	.039	.052	.060	....	.002	.035	.037
8,000	....	.034	.036	.129	....	....	.025	.038
9,000	....	.010	.048	.094	....	....	.015	.033
10,000	....	....	.029	.126	....	....	.015	.035

While the data in the tables are somewhat irregular on account of the comparatively small number of plants used, a few facts come out rather clearly. Probably the most conspicuous of these is the relatively high toxicity of sodium chlorid (NaCl) in Greenville soil when compared with other salts.

Two thousand p. p. m., or 0.2 per cent, marked the limit of growth for wheat, while three thousand p. p. m. was the limit for sugar beets. There was germination and growth with considerably more sodium carbonate (Na_2CO_3) than sodium chlorid, although the carbonate dissolved the organic matter from the soil, producing a very bad physical condition. Magnesium sulphate ($MgSO_4$) was only slightly toxic at a concentration of 1 per cent of the soil, while sodium sulphate (Na_2SO_4) was more toxic, but produced fair crops where 1 per cent was present. The percentage of germination, the height of plants, and the dry weight all correspond in showing where the growth began to be retarded by salt.

In order to determine the effect of the percentage of soil moisture on the toxicity of alkali, tests were made with soils having 12.5, 15, 17.5, 20, 22.5, 25, 27.5, and 30 per cent of water on the dry basis. At the one extreme the soil was about as dry as plants would grow in, while at the other it was completely saturated. The soil used was Greenville loam, and the seed planted was New Zealand wheat. The methods were the same as those already described, with 10 seeds in each glass.

The seeds were planted on August 16 and the plants harvested on September 27. The results are shown in Table IV.

TABLE IV.—*Effect of soil moisture on the toxicity of sodium carbonate on wheat plants*

Concentration of sodium carbonate (p. p. m. of dry soil).	Percentage of soil moisture.							
	12.5	15	17.5	20	22.5	25	27.5	30
NUMBER OF SEEDS GERMINATED IN EACH GLASS								
4,000	8	9	9	9	9	8	7	9
5,000	8	8	8	8	7	6	6	10
6,000	2	9	9	7	5	9	7	8
7,000	4	3	8	5	6	5	3	5
8,000	1	8	7	6	4	3	3	4
9,000	....	5	5	5	3	3	1	1
10,000	....	....	3	5	5	4	3	1
11,000	1	1	2	4	3	3	2	1
AVERAGE HEIGHT OF PLANTS (CENTIMETERS)								
4,000	14	20	23	29	25	27	25	26
5,000	12	19	24	23	24	25	24	27
6,000	10	20	21	21	19	23	22	26
7,000	7	6	20	10	14	21	10	12
8,000	1	8	8	8	8	13	16	7
9,000	....	5	5	4	4	5	7	4
10,000	....	0	1	3	3	8	7	1
11,000	1	1	2	3	2	4	3	4
DRY MATTER PRODUCED PER GLASS (GRAMS)								
4,000	0.090	0.136	0.147	0.216	0.197	0.166	0.155	0.196
5,000	.072	.123	.125	.131	.131	.120	.112	.202
6,000	.028	.131	.145	.113	.097	.145	.137	.154
7,000	.026	.018	.139	.046	.090	.085	.050	.078
8,000	0	.040	.055	.051	.048	.055	.074	.052
9,000	0	.019	.026	.024	.019	.035	.043	.021
10,000	0	0	.011	.008	.018	.065	.036	.028
11,000	.001	.001	.010	.019	.013	.014	.016	.025

From Table IV it is seen that the number of seeds germinating, the average height of plants, and the dry matter produced all decrease with the increased concentration of the alkali. The plants appear able to endure alkali better with a fair supply of moisture in the soil than where the soil is dry. This may be due to the fact that the soil solution is diluted by the water. Where the soil moisture was as low as 12.5 per cent, growth practically ceased at 7,000 p. p. m. of sodium carbonate, but in the wetter soils there was growth with as high a concentration as 11,000 p. p. m.

RESULTS IN 1913

On account of the inability to use a large number of seeds in glass tumblers, germination tests were made in tin plates in which 100 seeds could be used. An equivalent of 150 gm. of dry soil was placed in each tin plate and the necessary quantity of dry salt added. The salt was well mixed into the soil, which was made up to about 20 per cent of moisture. The seeds were planted and the pans covered with glass to prevent the escape of moisture. The number of seeds germinating was determined every day for three weeks. The results are summarized in Table V.

TABLE V.—*Percentage of germination of seeds of New Zealand wheat which germinated in 21 days in Greenville soil containing various alkali salts. Salts added dry*

Concentration of salt (p. p. m. of dry soil).	Percentage of germination.					
	Sodium chlorid.	Sodium carbonate.	Sodium sulphate.	Magnesium sulphate.	Equal parts of sodium chlorid, sodium carbonate, sodium sulphate, and magnesium sulphate.	Equal parts of sodium chlorid, sodium carbonate, sodium sulphate, and magnesium sulphate+1 per cent of calcium sulphate.
None	92	92	92	92	92	92
2,000	65	84	100	89	88	86
4,000	6	92	91	89	86	83
6,000	2	81	69	90	63	47
8,000	0	88	53	91	13	13
10,000	0	99	12	86	8	0
12,000	0	62	14	92	0	0
14,000	0	21	17	85	0	0
16,000	0	7	2	79	0	0
18,000	0	4	0	88	0	0
20,000	0	0	1	83	0	0

On examining Table V it is seen that sodium chlorid was by far the most toxic of the alkali salts and magnesium sulphate the least. The data given can not be taken as final, since all of the salts were not entirely dissolved and white salts could be seen scattered throughout the soil. The low harmfulness of sodium carbonate was probably due in part to the fact that it is not so readily soluble as the other salts when applied dry. The mixed salts were more harmful than any single salt, with the exception of sodium chlorid, and it is probable that the harmfulness of the mixed salts was due largely to the sodium chlorid.

Since there was such a great difference in the effects of the various salts, a second experiment was made to determine more exactly the critical point of concentration. The results of this test are summarized in Table VI.

TABLE VI.—*Percentage of germination of New Zealand wheat in soil containing alkali salts in different quantities. Salts added dry*

Sodium chlorid.		Sodium carbonate.		Sodium sulphate.		Magnesium sulphate.		Equal parts of sodium chlorid, sodium carbonate, sodium sulphate, and magnesium sulphate.		Equal parts of sodium chlorid, sodium carbonate, sodium sulphate, and magnesium sulphate + 1 per cent of calcium sulphate.	
P. p. m.	Seed germination.	P. p. m.	Seed germination.	P. p. m.	Seed germination.	P. p. m.	Seed germination.	P. p. m.	Seed germination.	P. p. m.	Seed germination.
	P. ct.		*P. ct.*		*P. ct.*		*P. ct.*		*P. ct.*		*P. ct.*
None.	92	None.	92	None.	92	None.	92	None.	92	None.	92
800	81	10,000	81	2,000	80	12,000	86	4,000	77	1,000	77
1,600	82	11,100	64	4,000	83	14,000	79	5,000	78	2,000	79
2,400	76	12,200	66	6,000	85	16,000	75	6,000	54	3,000	79
3,200	50	13,300	32	8,000	79	18,000	82	7,000	51	4,000	79
4,000	13	14,400	50	10,000	69	20,000	81	8,000	76	5,000	73
4,800	6	15,500	36	12,000	43	22,000	78	9,000	19	6,000	75
5,600	7	16,600	38	14,000	20	24,000	87	10,000	12	7,000	68
6,400	0	17,700	23	16,000	16	26,000	66	11,000	6	8,000	46
7,200	0	18,800	13	18,000	3	28,000	56	12,000	10	9,000	38
8,000	0	19,900	1	20,000	0	30,000	57	13,000	1	10,000	13

An examination of Table VI, in agreement with Table V, shows the germination to be greatly reduced by sodium chlorid in concentrations above 3,000 p. p. m., while it ceases entirely at about 6,000 p. p. m. With sodium carbonate a large reduction in germination occurred at about 10,000 p. p. m., but a few plants survived at about 20,000 p. p. m. The sodium sulphate showed about the same results as the sodium carbonate, while the magnesium sulphate gave over a 50 per cent germination at a concentration of 30,000 p. p. m. In the mixed salts the gypsum (calcium sulphate) did not have any great effect, possibly owing to the slowness with which gypsum dissolves.

On comparing the data in Tables V and VI with those reported in Table I and also others given later in the paper, where the salts were first dissolved and added in solution, it will be found that the salts were more toxic when added in solution than when mixed with the dry soil. This may be due to the slow solution and diffusion of the salt when added dry, which probably helps to explain the common observation that crops can sometimes be made to grow in a soil the analysis of which shows a very high total alkali content. It also explains why it is that crops growing on alkali land may look healthy and be growing vigorously until irrigated, when they are immediately killed.

In order to determine more exactly the effect of soil moisture on the toxicity of alkali salts, sand was placed in tin plates, as previously

described. To this sand salts were added in solution with the quantity of water necessary to bring the sand to the desired moisture content. Twenty-five kernels of Turkey Red wheat were planted in each pan, which was then covered with window glass to retain the moisture. Any loss in moisture was made up from time to time. The percentage of germination at the end of three weeks is given in Table VII.

TABLE VII.—*Percentage of germination at the end of three weeks of the seeds of Turkey Red wheat in sand with different quantities of moisture and alkali salts. Salts added in solution*

Salt and concentration (p. p. m. of dry soil).	Percentage of water in sand.				
	12	15	18	21	24
Sodium chlorid:					
None	75	80	84	84	78
800	92	80	72	88	80
1,800	48	80	88	76	48
2,400	28	60	88	80	60
2,900	4	24	68	64	44
3,600	0	0	84	12	16
4,000	0	0	36	0	8
4,500	0	0	6	0	0
5,700	0	0	4	0	0
6,000	0	0	0	0	0
Sodium carbonate:					
None	75	80	84	84	78
1,200	72	68	72	84	76
1,600	44	56	56	60	64
2,000	28	36	32	44	56
2,700	8	4	4	24	24
3,300	0	0	0	4	4
4,000	0	0	0	0	0
4,700	0	0	0	0	0
Sodium sulphate:					
None	75	80	84	84	78
2,000	88	88	92	96	88
4,000	36	72	80	92	68
6,000	12	60	72	72	72
8,000	8	4	20	44	64
10,000	0	0	28	36	36
12,000	0	0	0	12	20
14,000	0	0	0	0	4
16,000	0	0	0	0	4
18,000	0	0	0	0	0
Magnesium sulphate:					
None	75	80	84	84	78
12,000	20	24	40	28	56
14,000	16	12	48	48	60
16,000	12	16	48	52	48
18,000	4	8	20	44	40
20,000	0	4	8	16	48
22,000	0	0	0	12	12
24,000	0	0	0	12	12
26,000	0	0	0	0	4
28,000	0	0	0	0	0

From Table VII it will be seen that germination was first retarded by the salts when the soils contained but a small amount of moisture. With most of the salts the highest germination was in the wettest sand, while with sodium chlorid the intermediate moisture gave the highest germination.

It will be noted that in the sand sodium carbonate was more toxic than sodium chlorid. This same relation is also reported later in this paper with sand, although in all the tests with loam sodium chlorid was more toxic than sodium carbonate. A comparison of the limits of growth in sand with those already reported for loam brings out the fact that germination is reduced by a much lower concentration in sand than in loam. This is also brought out clearly in results reported later.

OUTLINE OF LATER WORK

GENERAL METHODS OF EXPERIMENTATION

A number of experiments were conducted in glass tumblers in which an equivalent of 200 gm. of dry soil was placed. Salts were added to the soil as follows: A stock solution of each salt was made up, containing an equivalent of 10 per cent of the anhydrous salt. The necessary quantity of the stock solution was then added to sufficient distilled water to make the soil up to 20 per cent water on the dry basis. The water containing the solution was thoroughly mixed with the soil on oilcloth and the whole placed in the glass. This method insured an even distribution of the salt through the soil.

In all cases the soil was made up to 20 per cent with moisture. This was about the optimum amount for plant growth. Ten seeds were planted in each glass to a depth of ½ inch from the surface. After the seeds were planted the glass tumblers were covered with panes of window glass until the plants were up. This prevented evaporation and enabled the seeds to germinate with an even soil-moisture content.

Counts were made of the number of plants up each day, which made possible a determination of the relative time required for germination in the different treatments. The original moisture content was maintained by adding the necessary quantity of water every day or two. The plants were allowed to grow for two or three weeks, when they were harvested and measured and the dry weights determined.

The data obtained for each glass therefore included (1) the percentage of germination, (2) the average time required for germination, (3) the average height of plants, (4) the average number of leaves, and (5) the dry matter produced.

In each test there were 15 glasses for each concentration of salts, and there were 10 concentrations. In addition, there were four check glasses to which no salt was added. This made 154 glasses for each test. In the series there were 24 tests, which gave a total of 3,696 glasses.

Five determinations were made of the plants in each glass, making about 18,450 separate determinations. This number was reduced somewhat by the fact that plants did not germinate in all the glasses, owing to the high salt content. With this great number of results it is impracticable to give all the data in detail; hence, only summaries will be presented.

COMBINATION OF SALTS

In each test containing 15 glasses three different salts were used. The glasses were arranged in the triangular diagram used in expressing

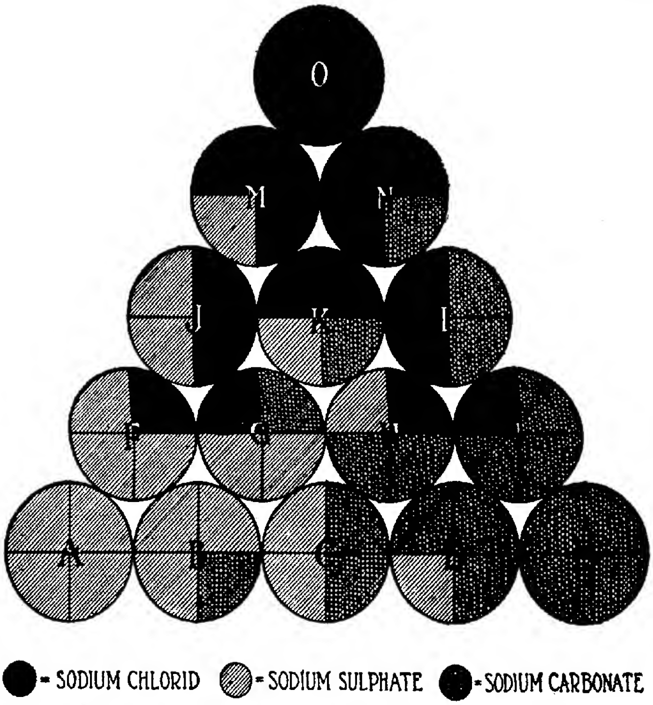


FIG. 1.—Diagram showing percentage of salts, mixtures, and their position in the diagrams of experimental sets. The arrangement of salts shown here is that in figure 2, page 14. The same positions but with different salts apply to figures 2 to 25.

three variables. This arrangement is shown in figure 1, the salts in this case being sodium sulphate, sodium carbonate, and sodium chlorid. All 15 glasses contain the same total concentration of salts—for example, in figure 1 the concentration is 1,000 parts of salt per million parts of dry soil.

The glasses on the corners of the diagram which are marked "A," "E," and "O" contained 100 per cent of the single salts. The other glasses

along the sides contained a mixture of two salts, while the glasses in the center contained all three salts in the proportions indicated.

It will be noted that the top glass (O) contained 100 per cent of sodium chlorid, the second row, with glasses M and N, 75 per cent of sodium chlorid, the third row, with glasses J, K, and L, 50 per cent of sodium chlorid, the fourth row, with glasses F, G, H, and I, 25 per cent of sodium chlorid, while the bottom row contained no sodium chlorid. The same order is followed with each of the other salts. Thus, there are glasses with each of the single salts, others with two salts in various combinations, and still others with all three salts in different proportions. From this arrangement it is possible to determine the effects of the single salts as well as the various combinations of salts.

In order to find the effects of the concentration of salts, 10 different concentrations were tried for each three salts. These varied from 1,000 to 10,000 p. p. m. of salt based on the dry soil. The combination of salts, as well as the soils and crops, are given in Table VIII.

TABLE VIII.—*Combinations of salts, soils, and crops used in concentration experiments*

Trial No.	Combination of salts.	Soil.	Crop.
1	Sodium chlorid, sodium sulphate, sodium carbonate	Greenville loam	New Zealand wheat.
2	Potassium chlorid, calcium chlorid, magnesium chlorid.	do	Do.
3	Sodium nitrate, potassium nitrate, magnesium nitrate.	do	Do.
4	Sodium sulphate, potassium sulphate, magnesium sulphate.	do	Do.
5	Potassium carbonate, sodium carbonate, ammonium carbonate $(NH_4)_2CO_3$.[a]	do	Do.
6	Sodium chlorid, sodium sulphate, sodium carbonate	Coarse sand	Do.
7	Potassium chlorid, calcium chlorid, magnesium chlorid.	do	Do.
8	Sodium nitrate, potassium nitrate, magnesium nitrate.	do	Do.
9	Sodium sulphate, potassium sulphate, magnesium sulphate.	do	Do.
10	Potassium carbonate, sodium carbonate, ammonium carbonate.	do	Do.
11	Sodium chlorid, sodium sulphate, sodium carbonate	College loam	Do.
12	Potassium chlorid, calcium chlorid, magnesium chlorid.	do	Do.
13	Sodium nitrate, potassium nitrate, magnesium nitrate.	do	Do.
14	Sodium sulphate, potassium sulphate, magnesium sulphate.	do	Do.
15	Potassium carbonate, sodium carbonate, ammonium carbonate.	do	Do.
16	Sodium chlorid, sodium sulphate, sodium carbonate	Greenville loam	Chevalier barley.
17	Do	do	White flint corn.
18	Do	do	Danish oats.
19	Do	do	Sugar beets.
20	Do	do	Alfalfa.
21	Do	do	Canada field peas.
22	Do	Distilled water	New Zealand wheat.
23	Potassium chlorid, calcium chlorid, magnesium chlorid.	do	Do.
24	Sodium nitrate, potassium nitrate, magnesium nitrate.	do	Do.

[a] The ammonium carbonate used has the formula $(NH_4)_2CO_3(NH_4)_2CO_2NH_2$, but the simpler formula, $(NH_4)_2CO_3$, is used for convenience.

DESCRIPTION OF SOILS

The following analyses were made by members of the Utah Station staff from soils taken from the same fields as the soils used in the experiments. While the analyses are not of the exact soils used, they will be useful, since the soils in these fields are very uniform. See Tables IX and X.

TABLE IX.—*Chemical analysis of soils used (strong hydrochloric-acid digestion)* [1]

Constituent.	Greenville soil.	College loam.	Sand.
	Per cent.	*Per cent.*	*Per cent.*
Insoluble residue	42.18	66.69	51.06
Potash (K_2O)	.67	.55	.15
Soda (Na_2O)	.35	.49	.21
Lime (CaO_2)	16.88	7.41	17.43
Magnesia (MgO)	6.10	4.15	5.63
Iron oxid (Fe_2O_3)	3.03	2.93	.86
Alumina (Al_2O_3)	5.64	3.49	1.25
Phosphoric acid (P_2O_5)	.41	.25	.14
Sulphuric acid (H_2SO_4)	....	.07	.03
Carbon dioxid (CO_2)	19.83	7.62	20.73
Humus	.53	2.18	.23
Total nitrogen	.14	.15	.02

TABLE X.—*Physical analysis of soils used (determined with Yoder elutriator)*

[1] Constituent.	Greenville soil.	College loam.	Sand.
	Per cent.	*Per cent.*	*Per cent.*
Coarse sand (above 1 mm.)	9.84	17.69	70.49
Fine sand (1 to 0.03 mm.)	30.04	37.39	20.75
Coarse silt (0.03 to 0.01 mm.)	32.25	15.19	3.32
Medium silt (0.01 to 0.003 mm.)	12.30	10.36	1.54
Fine silt (0.003 to 0.001 mm.)	6.25	10.32	.81
Clay (below 0.001 mm.)	7.62	9.03	2.16
Real specific gravity	2.67	2.64	2.81
Apparent specific gravity	1.23	1.32	1.32

[1] For methods followed, *see* Wiley, H. W., et al. Official and provisional methods of analysis, Association of Official Agricultural Chemists. U. S. Dept. Agr., Bur. Chem., Bul. 107 (rev.), 272 p., 1908.

DETAILS OF GERMINATION OF PLANTS AND DRY MATTER PRODUCED

GREENVILLE SOIL

In accordance with the outline already given, five tests were made with Greenville soil, three different salts being used in each test. The arrangement of glasses, the number of seeds germinated, and the dry matter produced in each glass are given in figures 2, 3, 4, 5, and 6. The name of the salt is given at the corner of each triangle. The combination of

these salts can readily be determined by consulting figure 1. The number at the bottom of each triangle refers to the concentration of soluble salts in all the glasses of that triangle expressed in parts of anhydrous salt per million parts of dry soil.

An examination of figure 2 shows that some seeds germinated in all glasses up to a concentration of 4,000 p. p. m., but that at 5,000 p. p. m. there was no germination in the glass having all sodium chlorid, and only germination in one of the glasses with three-fourths sodium chlorid. In the part of the triangle toward the sodium chlorid the germination gradually decreased as the concentration increased. The sodium carbonate and sodium sulphate showed almost a complete germination up to 10,000 p. p. m., or 1 per cent of salt.

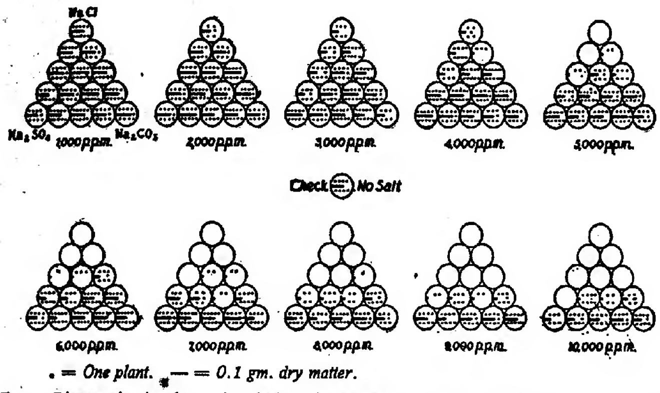


FIG. 2.—Diagram showing the number of wheat plants up and dry matter produced in 24 days on Greenville loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

The greater toxicity of sodium chlorid as compared with sodium carbonate was somewhat of a surprise, since most of the literature on alkali considers sodium carbonate, or black alkali, as being by far the most harmful of the alkali salts. The results given here agree with those found in the experiments of 1912 and 1913 and are also borne out by the results shown in figures 7, 12, 17, 18, 19, 20, 21, and 22, where different crops are compared.

In the glasses that received sodium carbonate the surface was black with dissolved humus and was somewhat crusted, showing that the physical condition had been injured. Notwithstanding this fact, seeds germinated in the soil and the plants grew for three weeks with no great injury except a slight blackening of plants at the surface of the soil with higher concentrations.

Figure 3 shows results for the chlorids of potassium, calcium, and magnesium. These chlorids are not as toxic as the chlorid of sodium,

but they are all more toxic than the sodium sulphate and sodium carbonate. Magnesium chlorid seemed to be the least toxic of the chlorids that were tested. Germination in all of them fell off rapidly above 4,000 p. p. m.

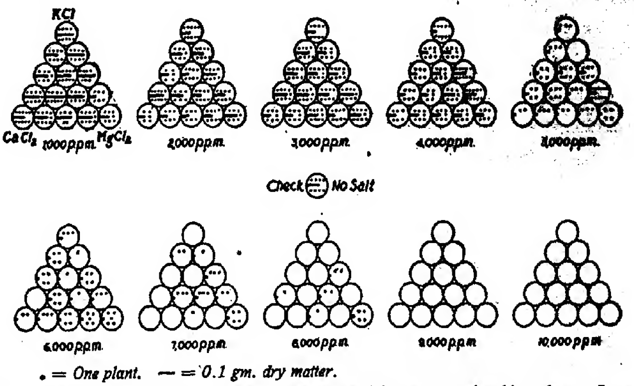


FIG. 3.—Diagram showing the number of wheat plants up and dry matter produced in 24 days on Greenville loam with calcium chlorid, magnesium chlorid, and potassium chlorid in different combinations and concentrations.

In figure 4 the nitrates of sodium, potassium, and magnesium are compared and the sodium found to be slightly more toxic than the others. The nitrates appear on the whole to be somewhat less toxic than the chlorids, but more so than the sulphates or carbonates.

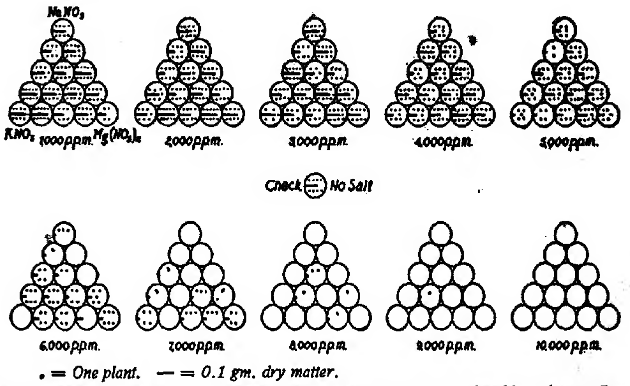


FIG. 4.—Diagram showing the number of wheat plants up and dry matter produced in 24 days on Greenville loam with potassium nitrate, magnesium nitrate, and sodium nitrate in different combinations and concentrations.

The results for the sulphates of sodium, potassium, and magnesium are given in figure 5. There was practically complete germination with all of the sulphates up to a concentration of 1 per cent; hence, but little difference in the three salts can be seen.

With the carbonates shown in figure 6 there is a marked falling off with the ammonium carbonate above 5,000 p. p. m. With the others there is a good germination up to 10,000 p. p. m., similar to the results shown in figure 2. The formula given by the manufacturers of the ammonium

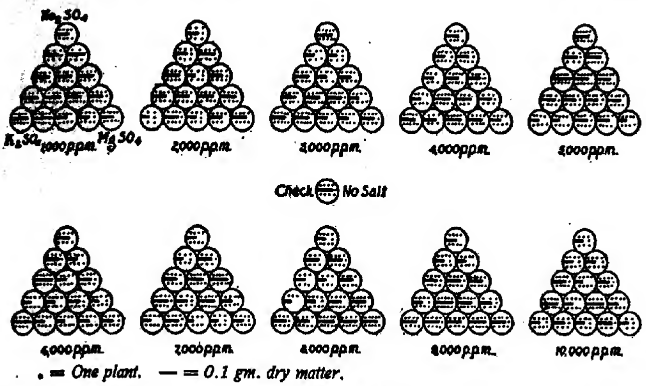


FIG. 5.—Diagram showing the number of wheat plants up and dry matter produced in 24 days on Greenville loam with potassium sulphate, magnesium sulphate, and sodium sulphate in different combinations and concentrations.

carbonate was $(NH_4)_2CO_3(NH_4)CO_2NH_2$ instead of the shorter formula, $(NH_4)_2CO_3$, given on the figures.

It is probable that the toxicity of the ammonium carbonate was due, in part at least, to the free ammonia that was constantly being given off

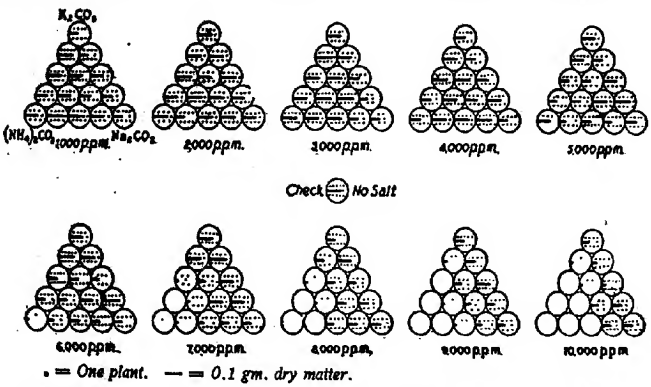


FIG. 6.—Diagram showing the number of wheat plants up and dry matter produced in 24 days on Greenville loam with ammonium carbonate, sodium carbonate, and potassium carbonate in different combinations and concentrations.

by this unstable compound rather than to the CO_3 part of the compound. It is a well-known fact that protoplasm is very sensitive to the action of free ammonia.

SAND

Five sets of tests were conducted with wheat growing in sand similar to those with the Greenville soil.

In figure 7 the results for sodium chlorid, sodium sulphate, and sodium carbonate are given. The noticeable thing about these results, as well

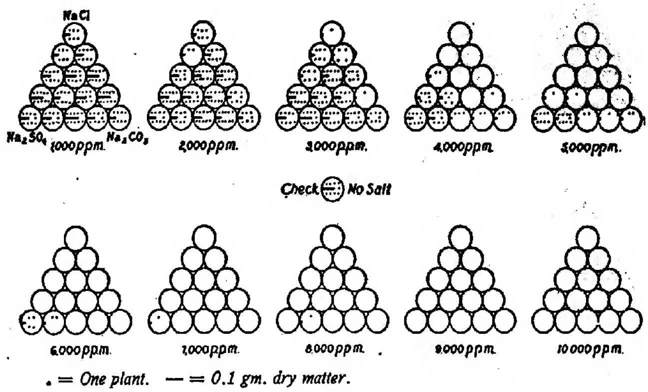


FIG. 7.—Diagram showing the number of wheat plants up and dry matter produced in 14 days on coarse sand with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

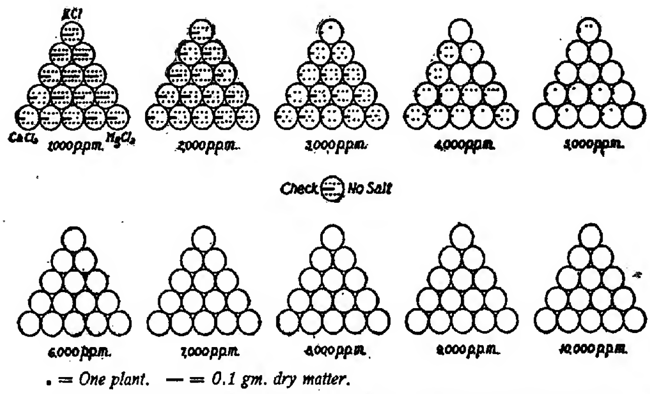


FIG. 8.—Diagram showing the number of wheat plants up and dry matter produced in 14 days on coarse sand with calcium chlorid, magnesium chlorid, and potassium chlorid in different combinations and concentrations.

as all those for sand, is that only about half as much salt is required to stop growth in sand as in either the Greenville soil or the College loam.

The same general relations between the salts are shown here as in the Greenville soil, except that in the sand sodium carbonate is propor-

tionately more toxic than in the other soils. This is exactly the same result that was obtained in 1913 in the experiments already described. In sand the carbonates seem to be nearly as toxic as the chlorids, while in the other soil they are very much less injurious.

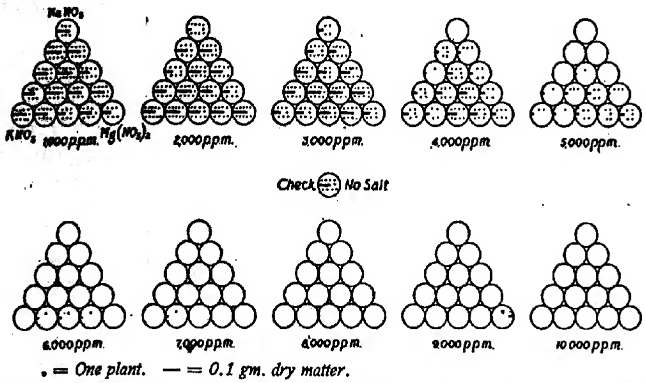


FIG. 9.—Diagram showing the number of wheat plants up and dry matter produced in 14 days on coarse sand with potassium nitrate, magnesium nitrate, and sodium nitrate in different combinations and concentrations.

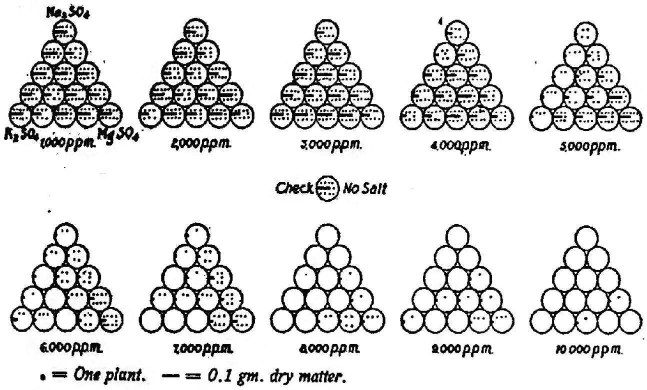


FIG. 10.—Diagram showing the number of wheat plants up and dry matter produced in 14 days on coarse sand with potassium sulphate, magnesium sulphate, and sodium sulphate in different combinations and concentrations.

Figure 8 shows the same relationship between the chlorids as was brought out in figure 3. It also shows that these salts are in injurious lower concentrations in sand than in other soils.

The nitrates are shown in figure 9 to be slightly less injurious than the chlorids in figure 8. The sodium salt is again shown to be more injurious than the others.

In sand the limit of growth in the presence of sulphates is shown by figure 10 to be less than 10,000 p. p. m., while in the loam growth was scarcely retarded at this concentration. Plants seem able to resist decidedly more magnesium sulphate than either potassium sulphate or

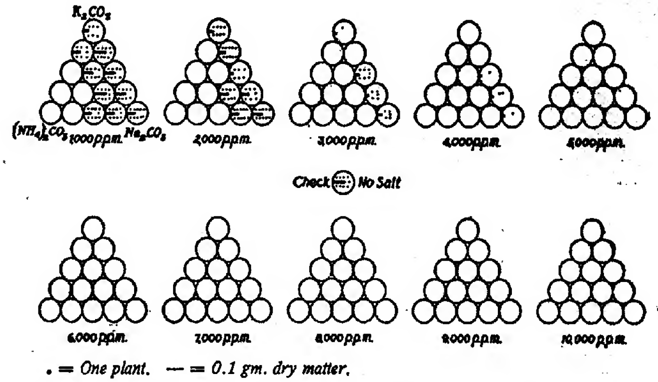


FIG. 11.—Diagram showing the number of wheat plants up and dry matter produced in 14 days on coarse sand with ammonium carbonate, sodium carbonate, and potassium carbonate in different combinations and concentrations.

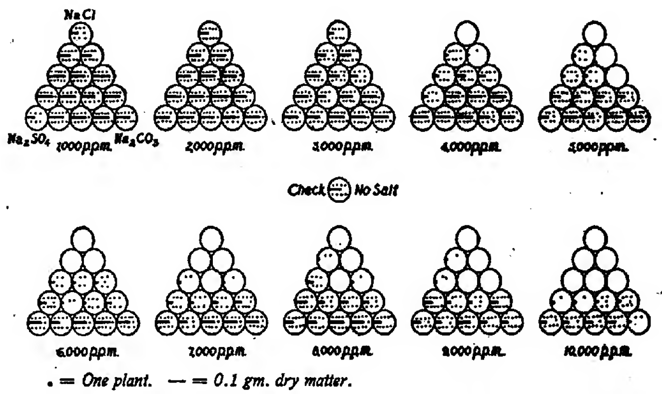


FIG. 12.—Diagram showing the number of wheat plants up and dry matter produced in 16 days on College loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

sodium sulphate. This is in accord with the earlier results found in 1912 and 1913.

Figure 11 shows that there was no germination whatever in sand where even as little as 1,000 p. p. m. of ammonium sulphate were found. With

any of the carbonates there was no germination for concentrations above 4,000 p. p. m.

COLLEGE LOAM

The same number of tests, using the same kinds of salts and seeds were conducted in College loam as in Greenville soil and sand. The

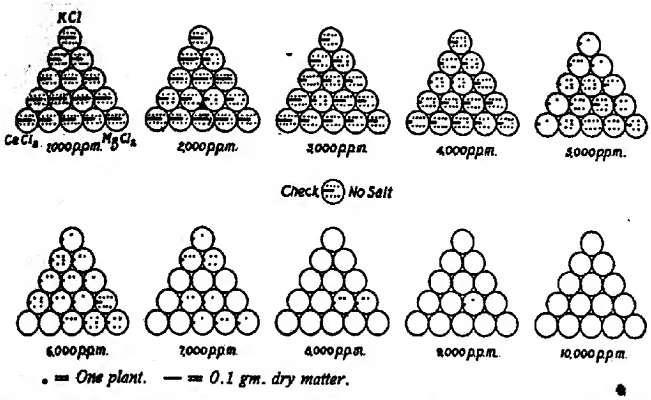


FIG. 13.—Diagram showing the number of wheat plants up and dry matter produced in 16 days on College loam with calcium chlorid, magnesium chlorid, and potassium chlorid in different combinations and concentrations.

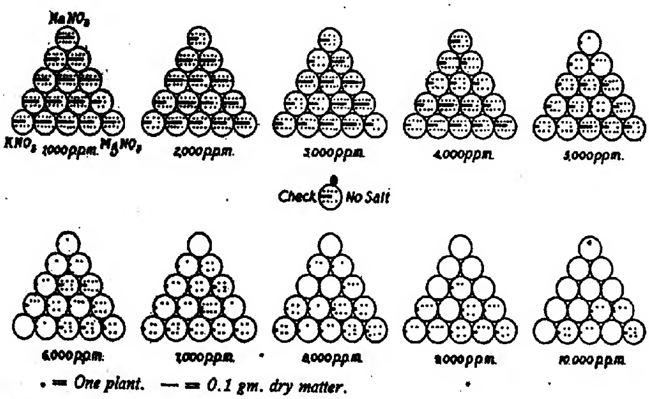


FIG. 14.—Diagram showing the number of wheat plants up and dry matter produced in 16 days on College loam with potassium nitrate, magnesium nitrate, and sodium nitrate in different combinations and concentrations.

results are shown in figures 12, 13, 14, 15, and 16. These results agree so completely with those found for the Greenville soil that individual comment seems unnecessary.

COMPARISON OF CROPS

In the management of alkali land it is important to know the relative resistances of various crops. Farmers who have been accustomed to deal with alkali are well aware that certain crops can be made to grow where others would be a complete failure.

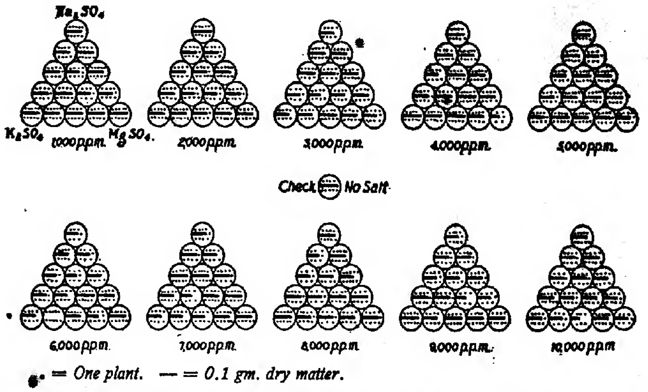


FIG. 15.—Diagram showing the number of wheat plants up and dry matter produced in 16 days on College loam with potassium sulphate, magnesium sulphate, and sodium sulphate in different combinations and concentrations.

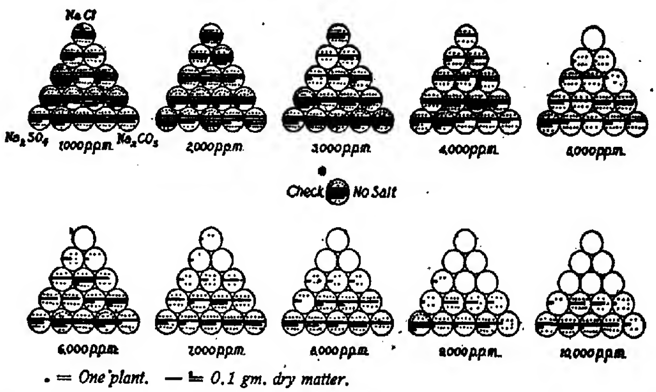


FIG. 16.—Diagram showing the number of wheat plants up and dry matter produced in 16 days on College loam with ammonium carbonate, sodium carbonate, and potassium carbonate in different combinations and concentrations.

A number of the common field crops were tested in the manner already described. Greenville soil was placed in glass tumblers and sodium chlorid, sodium sulphate, and sodium carbonate added in the same combinations and concentrations previously used. Ten seeds were

planted in each glass. The crops compared were wheat (*Triticum* spp.), barley (*Hordeum* spp.), oats (*Avena sativa*), corn (*Zea mays*), alfalfa (*Medicago sativa*), sugar beets (*Beta vulgaris*), and Canada field peas (*Pisum arvense*). The results for wheat have already been shown in

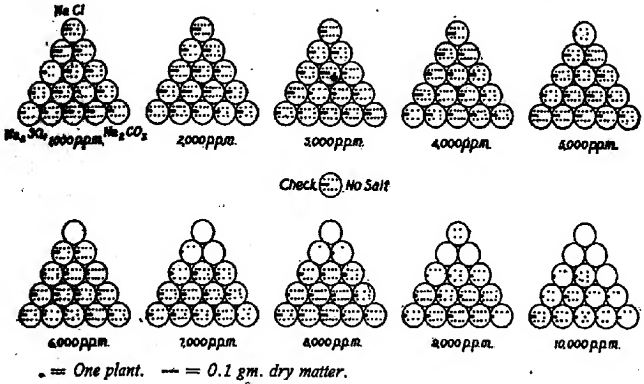


FIG. 17.—Diagram showing the number of barley plants up and dry matter produced in 24 days on Greenville loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

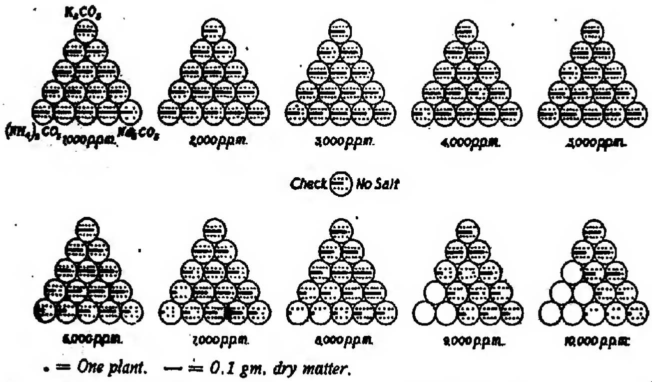


FIG. 18.—Diagram showing the number of corn plants up and dry matter produced in 21 days on Greenville loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

figure 2, while those for the other crops will be found in figures 17, 18, 19, 20, 21, and 22.

An examination of these diagrams shows that the relation between the salts, pointed out in connection with wheat, holds for the other crops.

According to the resistance of their seedlings to alkali, the crops fall into the following order: (1) Barley, (2) oats, (3) corn, (4) wheat, (5)

sugar beets, (6) alfalfa, and (7) Canada field peas. It may be that after the crops get a good start their resistance would not be in just this order; but in the percentage of seeds germinated this order seems to hold. Barley was able to withstand about twice as much alkali as field peas.

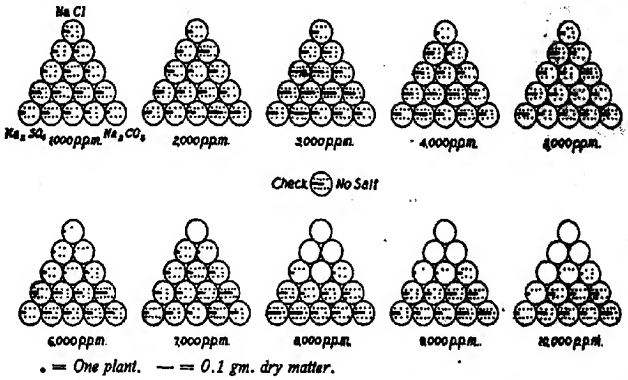


FIG. 19.—Diagram showing the number of oat plants up and dry matter produced in 21 days on Greenville loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

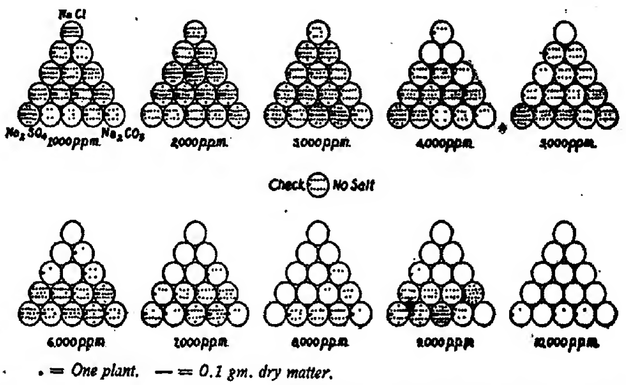


FIG. 20.—Diagram showing the number of sugar-beet plants up and dry matter produced in 21 days on Greenville loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

SOLUTION CULTURES

In order to compare the effect of salts in solution cultures with the same salts in soils, a number of tests were made with seedlings growing in distilled water to which various salts had been added. Glass tumblers were filled with water containing the proper quantity of the desired

solution. The glasses were then covered with paraffined paper which was bent over the edges and held in place by rubber bands. New Zealand wheat was germinated between moist filter papers until its roots were about half an inch long, when 10 seedlings to each glass were placed in

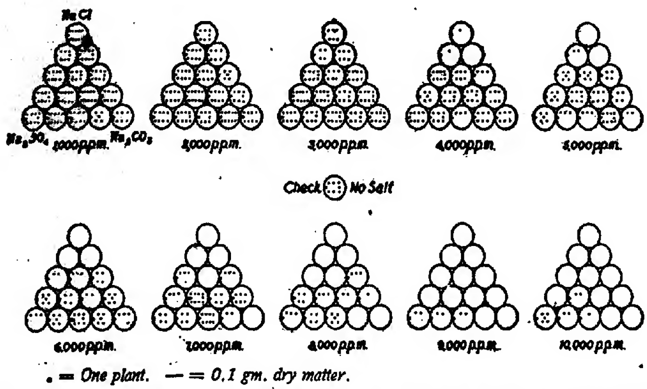


FIG. 21.—Diagram showing the number of alfalfa plants up and dry matter produced in 21 days on College loam with sodium sulphate, sodium carbonate, and sodium chlorid in different combinations and concentrations.

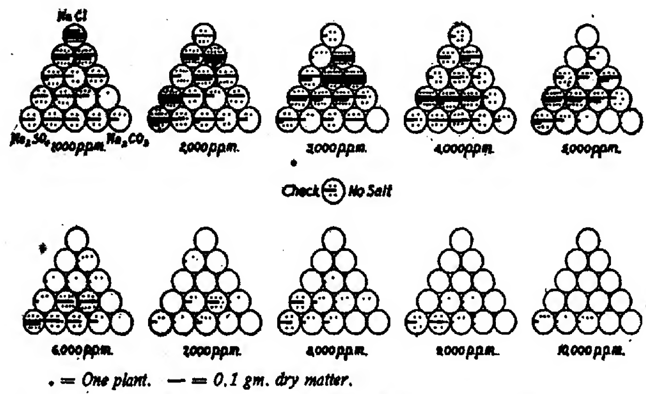


FIG. 22.—Diagram showing the number of Canada field-pea plants up and dry matter produced in 21 days on Greenville loam with sodium chlorid, sodium sulphate, and sodium carbonate in different combinations and concentrations.

holes in the paraffined paper, so that their roots grew down into the solutions.

The loss of water due to transpiration was made up every day or two.

The glasses were arranged in the triangular diagram as in the experiments with soils, which have already been discussed. In each test the

concentrations ranged from 1,000 parts of anhydrous salt for each 1,000,000 parts of water up to 10,000 p. p. m. of salt. The seedlings were allowed to grow 21 days before being harvested. At harvest the following determinations were made of the plants in each glass: (1) Plants still alive, (2) average height of plants, (3) average length of roots, (4) average number of leaves per plant, (5) dry weight of tops, (6) dry weight of roots, (7) ratio of length of tops to length of roots, (8) ratio of weight of tops to weight of roots.

In the first test sodium chlorid, sodium carbonate, and sodium sulphate, were used; in the second, potassium chlorid, calcium chlorid, and magnesium chlorid; and in the third, sodium nitrate, potassium nitrate, and magnesium nitrate. Figures 23, 24, and 25 show in detail the number of

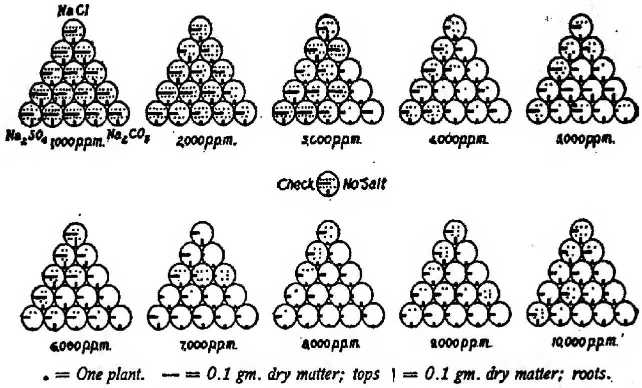


FIG. 23.—Diagram showing the number of seedlings alive and dry matter produced in tops and roots in 21 days with solutions of sodium chlorid, sodium sulphate, and sodium carbonate in different combinations and concentrations.

plants alive at the end of three weeks, as well as the weight of tops and roots in each glass.

An examination of the figures shows a gradual decrease in growth as the concentration of salts increased. Plants were able to endure much stronger chlorids and nitrates in solution culture than in the soil, while the carbonate retarded growth more in the solution than in the loam, but not as much as in the sand. The plants growing in the distilled water without any salts had no food except that stored in the seed and that dissolved from the glass, and, as a result, they produced less growth than plants growing in the dilute solutions.

The results showing the effect of concentration of the various salts are summarized in Table XI. Each figure represents the average of nine different salts of a given concentration. An examination of the table shows that the number of plants alive at the end of three weeks

decreased as the concentration of the solution increased, there being an average of 9.7 plants to each glass alive where no salt was added to the culture, but only 3.8 plants alive with 10,000 p. p. m. of salt.

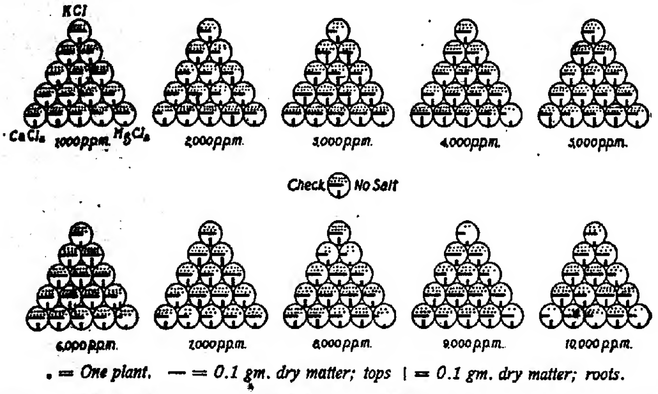


FIG. 24.—Diagram showing the number of wheat seedlings alive and dry matter produced in tops and roots in 21 days with solutions of potassium chlorid, calcium chlorid, and magnesium chlorid in different combinations and concentrations.

There was a corresponding decrease in number of leaves per plant, height of plants, length of roots, weight of tops, and weight of roots as the concentration of salts increased. The weight of roots, however, was not so much affected as some of the other results. In the cultures in

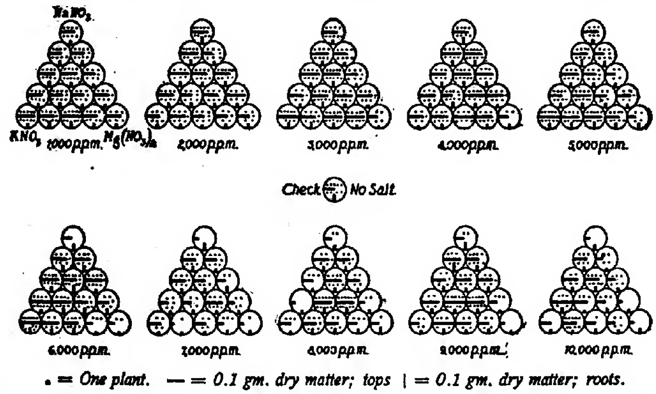


FIG. 25.—Diagram showing the number of wheat seedlings alive and dry matter produced in tops and roots in 21 days with solutions of sodium nitrate, potassium nitrate, and magnesium nitrate in different combinations and concentrations.

which no salts were added, the height of plants, the length of roots, and the dry matter produced were not so great as in the cultures containing salts in low concentrations.

TABLE XI.—*Effect of concentration of salts in solution cultures on the growth of wheat seedlings. Average of 45 glasses for each concentration, with sodium sulphate, sodium carbonate, sodium chlorid, calcium chlorid, potassium chlorid, potassium nitrate, magnesium nitrate, and sodium nitrate in various combinations*

Concentration of salts in solution.	Number of plants alive.	Number of leaves per plant.	Height of plants.	Length of roots.	Ratio of height to length of root.	Dry weight of tops.	Dry weight of roots.	Ratio of weight of tops to roots.
P. p. m.			*Inches.*	*Inches.*		*Gm.*	*Gm.*	
None	9.7	1.97	7.5	3.9	1.92:1	0.123	0.052	2.36:1
1,000	9.0	1.91	8.6	4.4	1.91:1	.143	.046	3.37:1
2,000	7.8	1.72	6.8	3.4	1.96:1	.123	.044	3.04:1
3,000	5.1	1.67	6.8	3.6	1.88:1	.137	.048	3.08:1
4,000	5.7	1.41	6.0	3.2	1.87:1	.123	.045	2.83:1
5,000	5.7	1.70	5.4	3.0	1.88:1	.118	.052	2.40:1
6,000	5.8	1.62	5.7	3.1	1.90:1	.133	.050	2.67:1
7,000	4.1	1.34	4.6	2.8	1.81:1	.100	.040	2.43:1
8,000	4.3	1.43	4.1	2.3	1.74:1	.096	.038	2.46:1
9,000	4.4	1.37	4.1	2.3	1.74:1	.105	.040	2.58:1
10,000	3.8	1.29	3.2	2.0	1.70:1	.100	.043	2.37:1

Table XII shows the effect of the individual salts when used alone. The results given in this table are the averages of various concentrations, from 1,000 to 10,000 p. p. m. In interpreting these figures it must be remembered that no nutrient solution was added where the single salt was present. Using the average height of plants as an index, the toxicity of the salts was in the following order: Sodium carbonate, sodium chlorid, magnesium nitrate, sodium sulphate, magnesium chlorid, sodium nitrate, potassium nitrate, potassium chlorid, and calcium chlorid.

TABLE XII.—*Growth of wheat seedlings in solution cultures of various salts. Average of 10 concentrations of each salt*

Salt.	Number of plants alive.	Average leaves per plant.	Height of plants.	Length of roots.	Ratio of height to root length.	Dry weight of tops.	Dry weight of roots.	Ratio of weight of tops to roots.
			In.	*In.*		*Gm.*	*Gm.*	
Sodium sulphate	4.8	1.4	4.2	2.2	1.91:1	0.096	0.044	2.18:1
Sodium carbonate	1.7	1.2	2.1	1.6	1.31:1	.063	.028	2.25:1
Sodium chlorid	5.2	1.3	3.1	2.0	1.55:1	.092	.046	2.00:1
Calcium chlorid	8.4	1.8	7.9	3.2	1.88:1	.130	.066	1.97:1
Magnesium chlorid	6.0	1.6	5.0	1.5	3.33:1	.109	.036	3.03:1
Potassium chlorid	7.1	1.6	6.2	2.6	2.38:1	.126	.051	2.47:1
Potassium nitrate	6.0	1.8	5.8	2.7	2.15:1	.154	.039	3.95:1
Magnesium nitrate	2.5	1.3	3.4	1.5	2.27:1	.073	.031	2.35:1
Sodium nitrate	4.4	1.5	5.4	2.7	2.00:1	.113	.041	2.76:1

A rather conspicuous point in the table is the high ratio of tops to roots, both as to length and weight, in the cultures containing magnesium chlorid. The roots were also very short with magnesium nitrate,

even more so than with sodium carbonate. This affirms the well-known toxicity of magnesium salts to roots when used alone. The various salts in solution cultures did not act at all in the same manner as in soils, which shows the inadvisability of applying too widely to the soil the results obtained with solution cultures of alkali.

RESULTS OF STUDIES

NUMBER OF SEEDS GERMINATED

In the five graphs which follow (fig. 26–30) the effects of various factors on the number of seeds germinating in each glass are given. These are all summaries and each one represents a great many figures. It will be remembered that 10 seeds were planted in each glass.

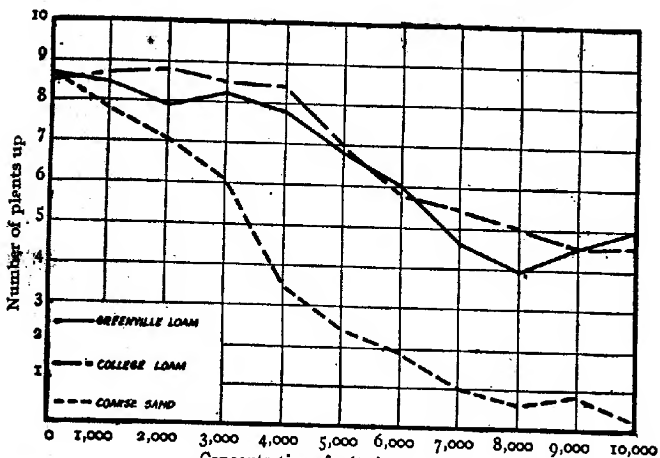


FIG. 26.—Curve showing the number of wheat plants germinating in College loam, Greenville loam, and sand with different concentrations. Average of 13 salts.

Figure 26 shows the effect of the concentration of salts in sand, Greenville loam, and College loam on the number of seeds germinating. Each curve represents the average of 13 salts in various combinations. In all of the soils there was an average of about 8½ plants coming up in each glass to which no salt was added. In sand the germination rapidly decreased with the concentration of salt, especially above 3,000 p. p. m. In College loam and Greenville loam there was but little falling off in germination until a concentration of over 4,000 p. p. m. had been reached.

Figure 27 shows the effect of the various salts on the germination of wheat in the three kinds of soil. Each salt represents the average of 10 concentrations ranging from 1,000 to 10,000 p. p. m. In sand there

was no germination whatever when ammonium carbonate was present even in as low a concentration as 1,000 p. p. m., but in the loams this

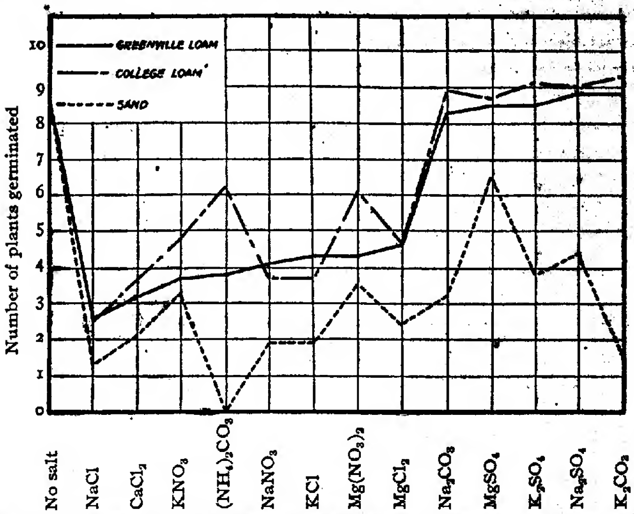
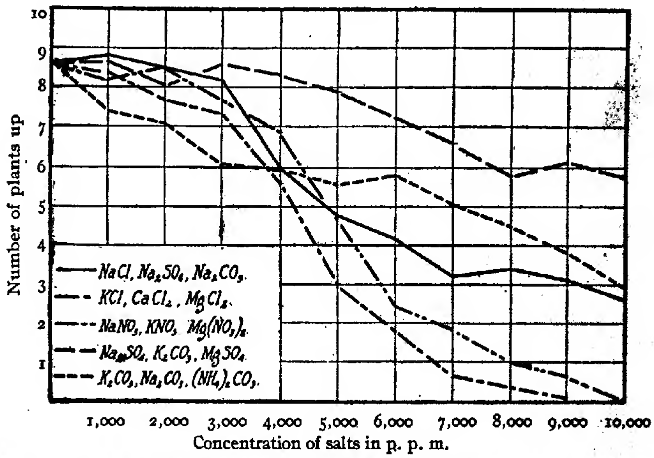


FIG. 27.—Curve showing the number of wheat plants germinating in College loam, Greenville loam, and sand containing various salts. Average for all concentrations.

salt was not so toxic as some of the chlorids. The salts are arranged in the order of their toxicity to germination in Greenville loam.



IG. 28.—Curve showing the effect of various combinations of salts in different concentrations on the number of wheat plants germinating. Average of 15 combinations.

Figure 28 gives results where three salts were present in the soils in various combinations. Potassium chlorid, calcium chlorid, and mag-

nesium chlorid retarded germination most of any of the salts that were used together, while sodium sulphate, potassium sulphate, and magnesium sulphate retarded it least. With the first three salts there was no germination whatever above 9,000 p. p. m. and less than one-third complete germination at a concentration of 5,000 p. p. m.

In figure 29 the effect of the concentration of sodium chlorid, sodium carbonate, and sodium sulphate on the different crops is shown. A striking feature of the table is the stimulating effect of these salts in low concentration on the germination of sugar beets. With the exception of sugar beets, all the crops showed considerable similarity. One reason for the high germination of beets is the number of germs in each seed

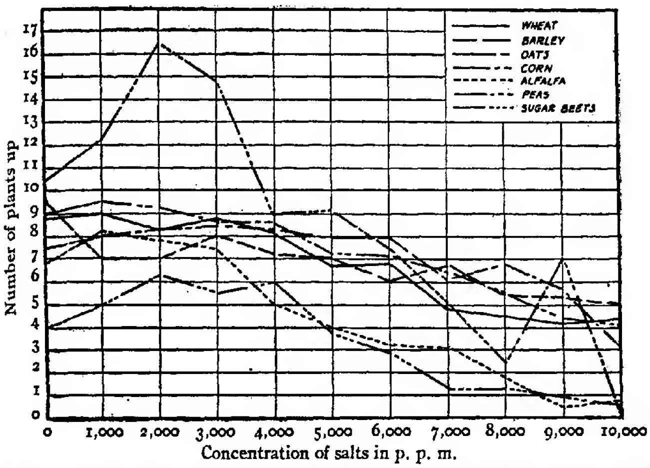


FIG. 29.—Curve showing the effect of concentration of salts on the number of seeds of various kinds germinating. Average for sodium chlorid, sodium carbonate, and sodium sulphate.

ball. Alfalfa and field peas were affected by the salts decidedly more than the cereals.

The individual effect of sodium chlorid, sodium carbonate, and sodium sulphate on the different crops is shown in figure 30. Sodium chlorid is seen to be rather uniformly toxic to all crops, while sodium carbonate varies greatly. Sugar beets seem to be particularly resistant to sodium sulphate.

DRY MATTER PRODUCED

The five curves which follow (fig. 31–35) show the same results for amounts of dry matter produced by each glass that were given for germination in the five preceding figures (fig. 25–30). The numbers given represent the dry weight of plant material produced in each glass.

Figure 31 shows that the production of dry matter was stimulated by the presence of 1,000 p. p. m. of salt in the Greenville and College loam, but was about the same in sand for 1,000 p. p. m. as where no salt was

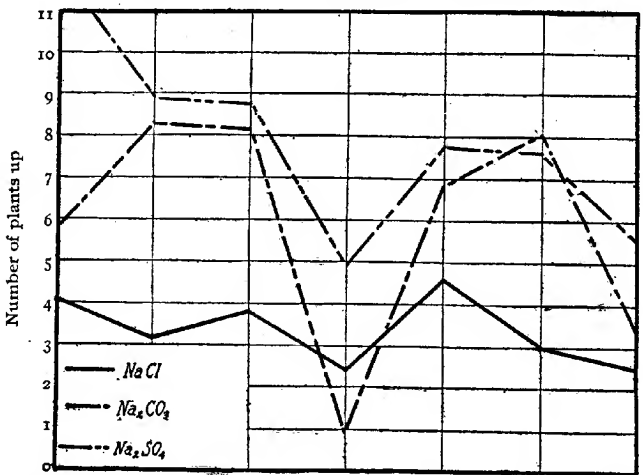


FIG. 30.—Curve showing the effect of sodium chlorid, sodium carbonate, and sodium sulphate on the number of plants up from seeds of various kinds. Average for concentrations from 1,000 to 10,000 p. p. m.

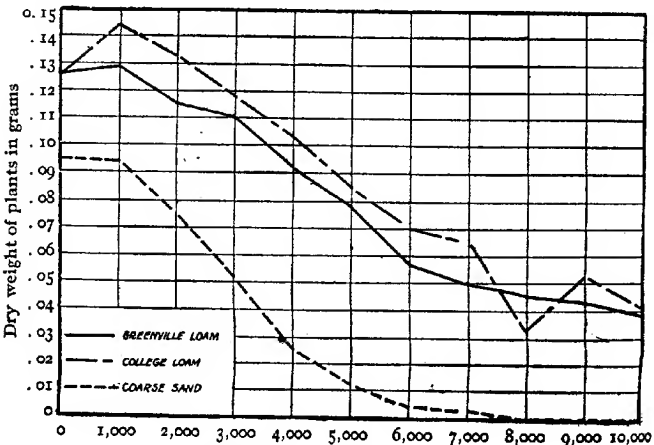


FIG. 31.—Curve showing the dry weight of wheat plants germinating in College loam, Greenville loam, and sand with different concentrations. Average of 13 salts.

added. The quantity of dry matter rapidly decreased with the concentration of salt above this point. In sand there was no plant growth at all above 8,000 p. p. m. of salt.

The effect of individual salts is shown in figure 32. A comparison of this graph with figure 27 shows that the dry matter is affected by the

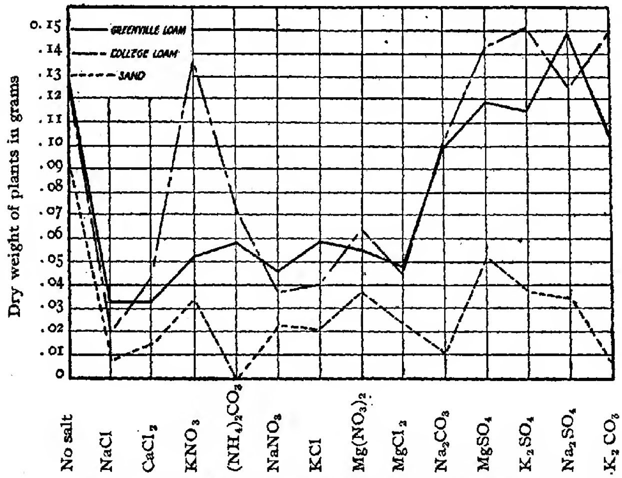


FIG. 32.—Curve showing the dry weight of wheat plants germinating in College loam, Greenville loam, and sand containing various salts. Average for all concentrations.

salt in just about the same way as the germination. The greater relative toxicity of the carbonates in sand than in loam is again brought out.

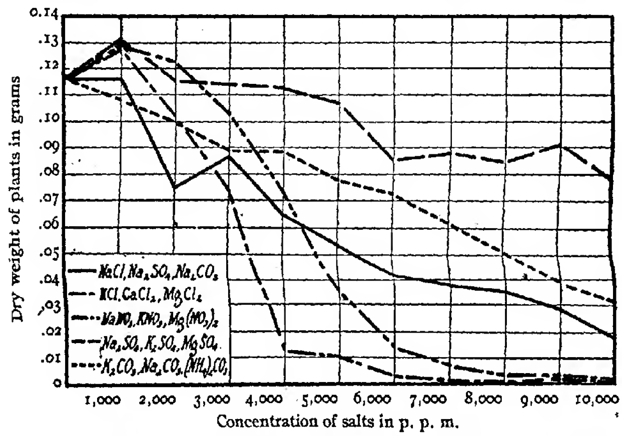


FIG. 33.—Curve showing the effect of various combinations of salts in different concentrations on the amount of dry weight produced. Average of 15 combinations of each 3 salts.

The action of each three salts used together is shown in figure 33. With the exception of potassium carbonate, sodium carbonate, and am-

monium carbonate the production of dry matter was stimulated by low concentrations of the salts. The growth of plants was not greatly reduced by the sulphates even in relatively high concentrations, while with the chlorids the yield dropped very rapidly and was practically nothing where the concentration was above 4,000 p. p. m.

Figure 34 shows the dry matter produced by different kinds of crops in soils containing sodium chlorid, sodium carbonate, and sodium sulphate in concentrations from 1,000 to 10,000 p. p. m. Corn gave by far the largest quantity of dry matter, but it was probably as much affected by the salt as any other crop. The yield was reduced from above 0.6 gm. per glass with no salt to less than 0.1 gm. per glass with a concentration of 10,000 p. p. m. Canada field peas produced a large quantity of dry

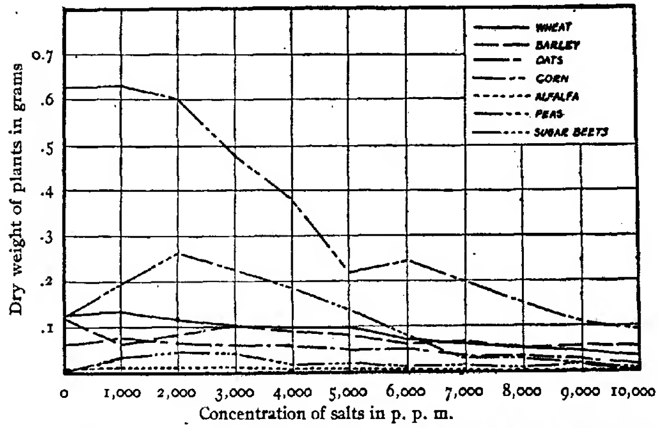


FIG. 34.—Curve showing the effect of concentration of salts on the dry weight of plants from seeds of various kinds. Average for sodium chlorid, sodium carbonate, and sodium sulphate.

matter, but they were also greatly affected by the concentration of salt. Alfalfa gave the least total yield under all conditions.

The effect of the individual salts on the yield of the various crops is brought out in figure 35. The yield of all crops was highest with sodium sulphate and lowest with sodium chlorid. With most crops it was only about half as great with sodium chlorid as with sodium carbonate.

DAYS TO COME UP

During the experiments a count was made each day of the number of plants that appeared above the surface of the soil, and from these figures a determination was made of the average time required for the plants in each glass to come up. The average results are in some cases misleading, because with toxic salts no plants germinated in the high concentration, and the averages were determined from the plants that came

up, which in this case were only those in low concentrations. At the same time there might be considerable germination in the high concentrations of less toxic salts, but the time of germination was increased. Thus, the average time of germination might appear to be longer in the less toxic salt, when in reality this would not be the case.

Figure 36 shows the time required for wheat to come up in Greenville loam, College loam, and sand containing salts in concentrations up to 10,000 p. p. m. The results are the average for 13 different salts. The time required to germinate where no salt was present varied from about 5½ to 6½ days with no salt and from 10½ to 15 days with 10,000 p. p. m.

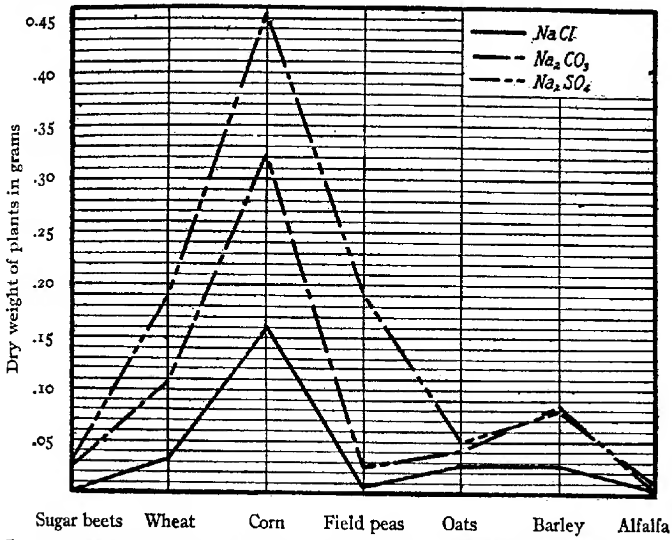


FIG. 35.—Curve showing the effect of sodium chlorid, sodium carbonate, and sodium sulphate on the dry weight from seeds of various kinds. Average for concentrations from 1,000 to 10,000 p. p. m.

of salt. The time was doubled by the presence of from 6,000 to 8,000 p. p. m. of salt.

Figure 37 shows the effect of individual salts on time of germination in the three kinds of soil. Calcium chlorid, magnesium chlorid, and sodium chlorid retarded germination most in Greenville soil, while sodium nitrate came next.

In sand the salts did not retard germination as much as in loam. This is because there was no germination whatever in sand with the highest concentration. There was no germination in sand when ammonium carbonate was added, even in as low concentrations as 1,000 p. p. m.

The results where three salts were used together are shown in figure 38. The average time of germination with potassium chlorid, calcium

chlorid, and magnesium chlorid in a concentration of 8,000 p. p. m. was over 20 days, which was nearly four times as long as the time required for seeds to come up where no salt was added. The period of germination was less with the sulphates and carbonates than with the other salts.

The time of germination of different crops in the presence of sodium chlorid, sodium carbonate, and sodium sulphate in combination is shown in figure 39. Where no salts were added, the time varied from about 4½ days for barley to nearly 8 days for sugar beets. The same general relation between the germination of various crops continued with the different concentrations of salts. Alfalfa was least affected by salts of any of the crops in the length of its germination period.

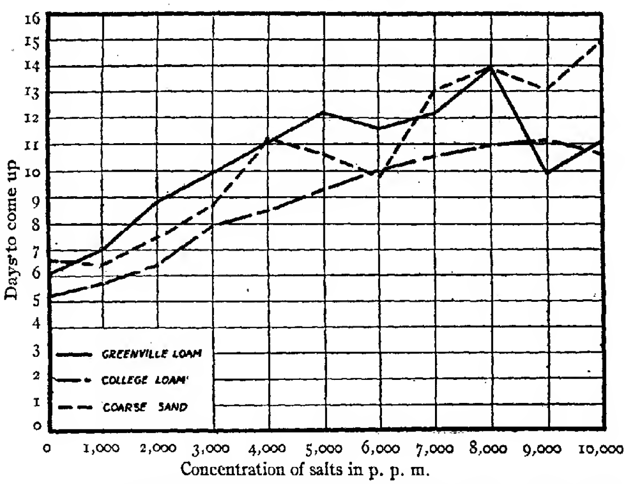


FIG. 36.—Curve showing the number of days for wheat plants to come up in College loam, Greenville loam and sand with different concentrations. Average of 13 salts.

Figure 40 shows the effects of individual salts on the germination period of different crops. This brings out again the fact already mentioned, that the same relative toxicity of salts does not hold for all crops.

HEIGHT OF PLANT

Figures 41, 42, 43, 44, and 45 show the effect of various factors on the height of plants. This is probably one of the best means of comparison for young plants of this kind.

Plants growing in sand were not so high in any case as those growing in other soils; in the Greenville loam they were slightly higher than in College loam. The height in loam was greater with 1,000 p. p. m. of salt than where no salt was added, but above this point the height decreased considerably as the concentration of salt increased. In sand

the height was much more affected by the salts than in loam. The rise in the curve at 10,000 p. p. m. is due to the fact that no plants grew at this concentration in the more toxic salts and not to the actual increase in height.

Figure 42 shows the effect of each salt in the three soils on the height of wheat. The same general results which have already been pointed out in connection with germination and dry-matter production are noted here. Potassium nitrate produced the shortest plants in the loams,

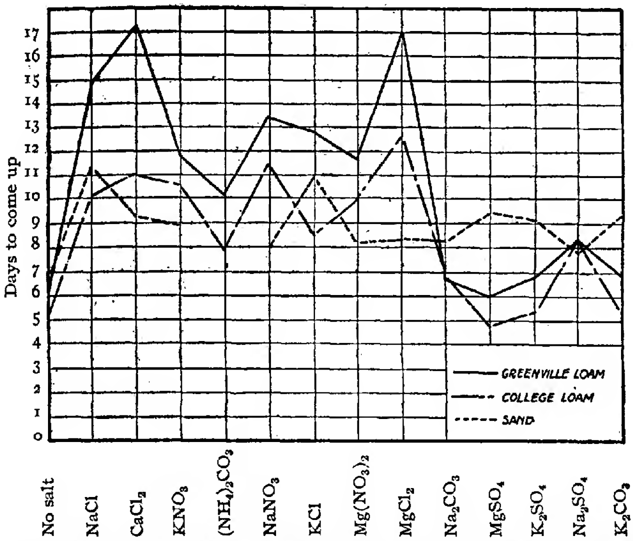


FIG. 37.—Curve showing the number of days for wheat plants to come up in College loam, Greenville loam, and sand containing various salts. Average for all concentrations.

while sodium chlorid and sodium carbonate produced the shortest plants in sand.

Figure 43 shows the height of plants in soils to which three salts in combinations of various kinds had been added. This diagram shows that the chlorids and nitrates had a great effect on the height of plants, while the carbonates and sulphates had less.

The effect of the concentrations of sodium chlorid and sodium sulphate on the height of different crops is shown in figure 44. While the curves are somewhat irregular, they show the same results that have already been brought out regarding the shortening of plants by alkali.

Figure 45 shows the effect of individual salts on the height of various crops. It will be noted that in practically all cases the crops were shorter where sodium chlorid was present than with the other salts; also that sodium sulphate usually gave the highest plants.

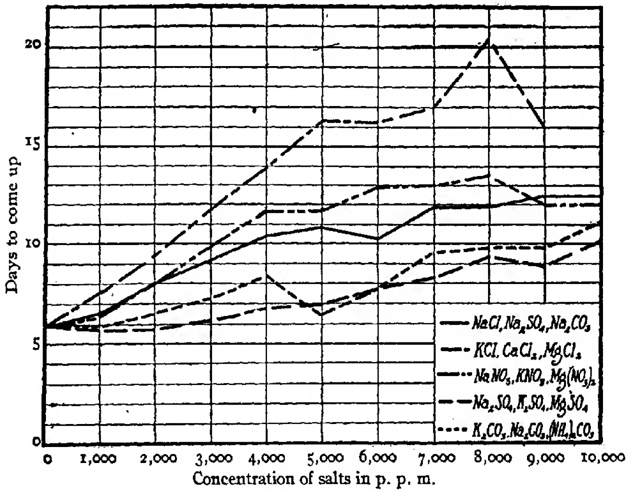


FIG. 38.—Curve showing the effect of various combinations of salts in different concentrations on the number of days to come up. Average of 15 combinations.

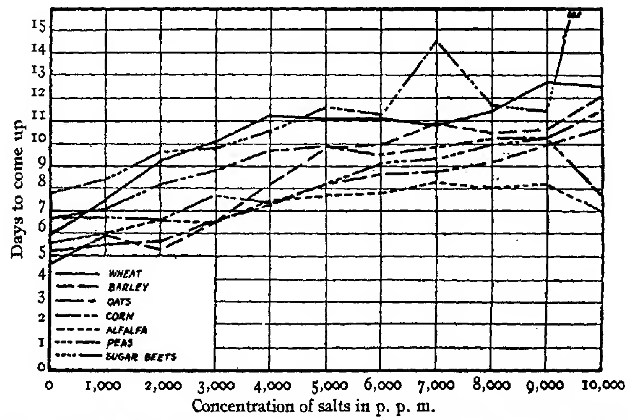


FIG. 39.—Curve showing the effect of concentration of salts on the number of days to come up from seeds of various kinds. Average for sodium chlorid, sodium carbonate, and sodium sulphate.

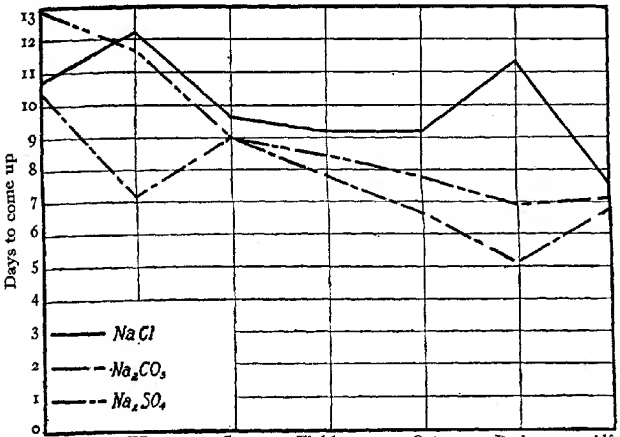


FIG. 40.—Curve showing the effect of sodium chlorid, sodium carbonate, and sodium sulphate on the number of days to come up from seeds of various kinds. Average for concentrations from 1,000 to 10,000 p. p. m.

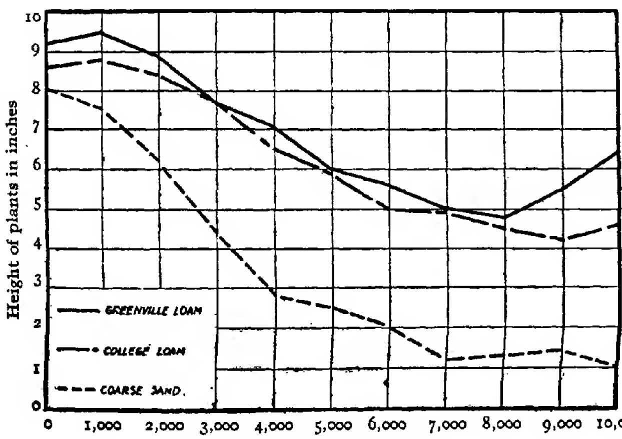


FIG. 41.—Curve showing the height of wheat plants germinating in College loam, Greenville loam, and sand with different concentrations. Average of 13 salts.

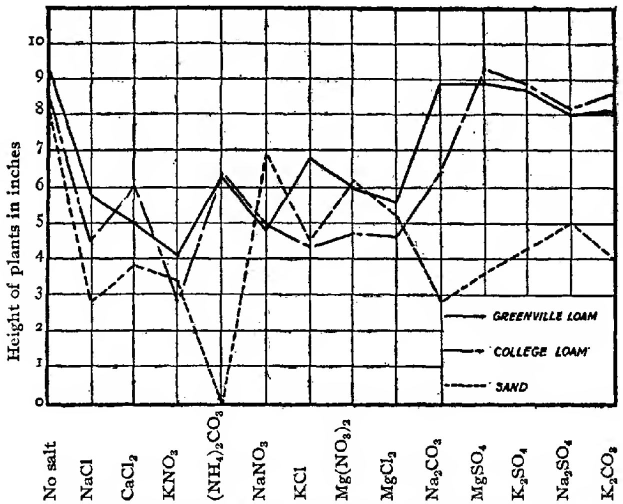


FIG. 42.—Curve showing the height of wheat plants germinating in College loam, Greenville loam, and sand containing various salts. Average for all concentrations.

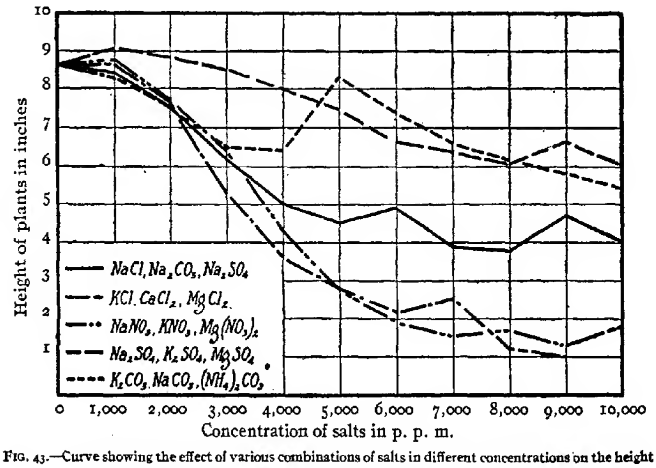


FIG. 43.—Curve showing the effect of various combinations of salts in different concentrations on the height of plants. Average of 15 combinations of each group of 3 salts.

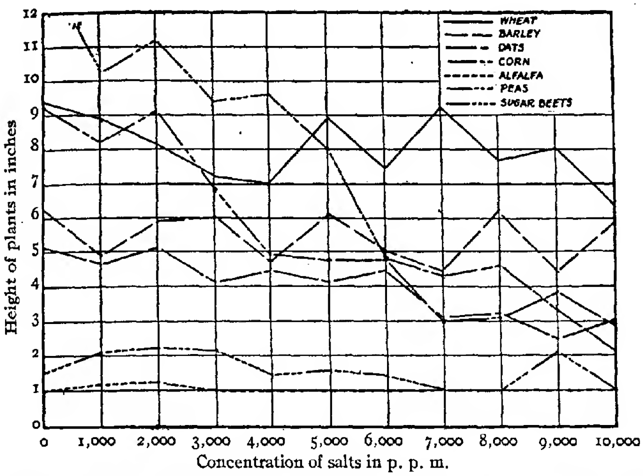


Fig. 44.—Curve showing the effect of concentration of salts on the height of plants from seeds of various kinds. Average for sodium chlorid, sodium carbonate, and sodium sulphate.

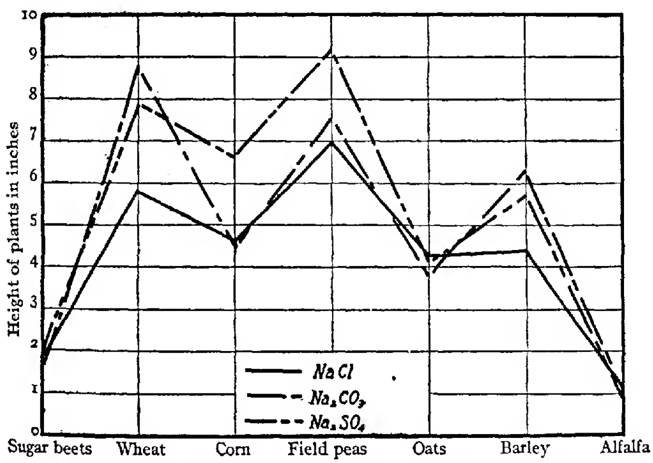


Fig. 45.—Curve showing the effect of sodium chlorid, sodium carbonate, and sodium sulphate on the height of plants from seeds of various kinds. Average for concentrations from 1,000 to 10,000 p. p. m.

ACTION OF THE VARIOUS IONS

COMPARISONS OF CATIONS AND ANIONS

In order to determine the effect of the different ions and to compare the relative action of the cations and anions, the results of the various tests were summarized and are presented in Tables XIII and XIV. These data represent the averages of the various concentrations of the salts in three different soils; hence, they should be fairly reliable.

On examining Table XIII it will be seen that the chlorid was by far the most toxic anion, followed by the nitrate, carbonate, and sulphate in the order named. This order held for all salts regardless of the basic ion, and is contrary to ideas on the subject previously held, as the carbonate was thought by many writers to be most injurious.

TABLE XIII.—*Effect of various anions on the germination and growth of wheat. Average for 3 soils and 10 concentrations for each soil*

Ions.	Number of trials.	Number of plants germinated.	Days to come up.	Average height of plants.	Average number of leaves per plant.	Weight of dry matter per glass.
				Inches.		*Gm.*
Sodium—						
Chlorid	30	2.3	11.2	4.3	1.35	0.020
Sulphate	30	7.0	9.0	7.0	1.77	.101
Carbonate	30	6.2	7.7	5.9	1.67	.072
Nitrate	30	3.3	8.6	5.5	1.62	.035
Average of sodium salts.	120	4.7	9.1	5.7	1.60	.057
Potassium—						
Chlorid	30	3.1	11.6	5.2	1.54	.040
Sulphate	30	7.1	6.5	7.3	1.75	.101
Carbonate	30	6.4	5.8	6.9	1.61	.087
Nitrate	30	3.7	9.0	3.4	1.29	.074
Average of potassium salts	120	5.1	8.5	5.7	1.55	.076
Magnesium—						
Chlorid	30	3.4	12.8	5.1	1.49	.039
Sulphate	30	7.9	6.7	7.3	1.72	.105
Carbonate	30	4.6	8.8	5.6	1.63	.052
Average of magnesium salts	90	5.3	9.4	6.0	1.61	.065
Calcium—						
Chlorid	30	2.8	12.1	4.9	1.66	.031
Ammonium—						
Carbonate	30	3.3	6.0	4.2	1.17	.044

In Table XIV a comparison is made of the various cations. Sodium is seen to be most injurious of all the bases except ammonium. Sodium is followed by calcium, potassium, and magnesium in the order named. This same order of toxicity held with all the acid radicals that were tried.

TABLE XIV.—*Effect of various cations on germination and growth of wheat. Average for 3 soils and 10 concentrations for each soil*

Cations.	Number of trials.	Number of plants germinated.	Days to come up.	Average height of plants.	Average number of leaves per plant.	Weight of dry matter per plant.
Chlorid—				*Inches.*		*Gm.*
Sodium	30	2.3	11.2	4.3	1.35	0.020
Potassium	30	3.1	11.6	5.2	1.54	.040
Calcium	30	2.8	12.1	4.9	1.66	.031
Magnesium	30	3.4	12.8	5.1	1.49	.039
Average of chlorids	120	2.9	11.9	4.9	1.51	.033
Sulphate—						
Sodium	30	7.0	9.0	7.0	1.77	.101
Potassium	30	7.1	6.5	7.3	1.75	.101
Magnesium	30	7.9	6.7	7.3	1.72	.105
Average of sulphates	90	7.3	7.4	7.2	1.75	.102
Carbonate—						
Sodium	30	6.2	7.7	6.0	1.67	.071
Potassium	30	6.4	6.8	6.9	1.61	.087
Ammonium	30	3.3	6.0	4.2	1.17	.044
Average of carbonates	90	5.3	6.8	5.7	1.48	.067
Nitrate—						
Sodium	30	3.3	8.6	5.5	1.62	.035
Potassium	30	3.9	9.0	3.4	1.29	.074
Magnesium	30	4.6	8.8	5.6	1.63	.052
Average of nitrates	90	3.9	8.8	4.8	1.51	.054

A comparison of the various data presented in Tables XIII and XIV brings out clearly the fact that the injurious effects of the alkali salts in soils may be attributed more to the anion, or acid radical, than to the cation, or basic radical. All the chlorids gave results very similar to each other. The same may be said of the sulphates and nitrates. The different salts of sodium or potassium, on the other hand, differed greatly, according to the acid radical combined with them. This is just opposite to the conclusions of Kearney and Cameron (13) based on solution cultures.

RELATION OF MOLECULAR WEIGHT IN TOXICITY

A number of workers have considered the toxicity of various alkali salts to be proportional to their osmotic pressure. In order to determine whether this were true, the different salts which had been tested were arranged in the order of their toxicity and the molecular weight of each placed opposite to ascertain whether there was any relation between the two. Of course, it is understood that the lower the molecular weight of a salt the more molecules there are in a solution containing a given per-

centage of salt, and the more molecules there are the greater will be the osmotic pressure, provided there is the same dissociation. Following out this reasoning, a salt of low molecular weight should be more toxic than one of higher molecular weight if the salts were present in the same percentage by weight. Indeed, in the study of osmosis, salts would not be expressed in percentages but in molecular solutions. In soils, however, it is impossible to express salts on a basis of molecular solution.

In Table XV it will be seen that in a general way salts with low molecular weights are more toxic than those having a higher molecular weight, but there are so many exceptions that this can not be considered a general law holding for all salts. For example, magnesium sulphate has a lower molecular weight than potassium sulphate, sodium sulphate, potassium carbonate, or magnesium nitrate, and yet it is less toxic than any of these salts.

TABLE XV.—*Comparison of the toxicity of the various salts with their molecular weight*

Salts in order of toxicity.	Number of plants germinated.	Weight of dry matter produced.	Molecular weight.
		Gm.	
Sodium chlorid	2.3	0.020	58.5
Calcium chlorid	2.8	.031	111.0
Potassium chlorid	3.1	.040	74.6
Sodium nitrate	3.3	.035	85.1
Ammonium carbonate	3.3	.044	202.2
Magnesium chlorid	3.4	.039	95.3
Potassium nitrate	3.9	.074	101.2
Magnesium nitrate	4.6	.052	148.4
Sodium carbonate	6.2	.071	106.1
Potassium carbonate	6.4	.087	138.3
Sodium sulphate	7.0	.101	142.2
Potassium sulphate	7.1	.101	174.4
Magnesium sulphate	7.9	.105	120.4

SALTS ALONE AND IN COMBINATION WITH OTHER SALTS

One of the most important questions arising in connection with the toxicity of alkali is regarding the action of salts when present alone and when in combination with other salts. Considerable work has been done on the antagonistic action of various salts in solution cultures, and some very remarkable results have been obtained; but many of these results do not hold when the salts are applied to the soil.

An examination of figures 2 to 24 will show that in the soil the antagonistic action of the various alkali salts is not so great as previous workers have found for these same salts in solutions. For example, the magnesium salts when used alone in solution are very toxic to plants, but this is largely overcome by the presence of other salts. The results for mag-

nesium salts in soils do not show them to be particularly toxic. This is probably due in part to the high lime content of the soils used.

An attempt is made in Table XVI to bring together a summary of results for salts applied to soil singly and in combination. These are grouped as sulphates, carbonates, nitrates, chlorids, and the sodium salts. Under each salt are given certain figures which, when multiplied by 1,000, give the parts per million of salt added to the soil. Each figure is the average for Greenville loam, College loam, and sand. The results include the number of plants germinating in each glass, the weight of dry plant material produced in each glass, the average height of plants, and the average number of days required for the plants to come up.

TABLE XVI.—*Effect of combination of salts on the germination and growth of wheat. Average of three soils*

[Figures under salts multiplied by 1,000 equal parts per million of salt in the soil]

Sulphates.

Sodium.	Potassium.	Magnesium.	Total salts.	Number of plants up.	Weight of dry matter produced.	Height.	Days to come up.
					Gm.	*In.*	
0	0	0	0	8.6	0.116	8.6	6.0
1	0	0	1	9.3	.127	8.1	6.7
0	1	0	1	9.7	.154	8.4	5.9
0	0	1	1	10.0	.135	9.3	5.0
1	½	½	2	7.7	.090	8.7	5.6
½	1	½	2	8.0	.109	8.4	5.7
½	½	1	2	8.0	.118	9.5	6.2
1	1	0	2	8.3	.117	8.4	6.3
0	1	1	2	7.7	.104	8.8	6.0
1	0	1	2	9.7	.126	8.8	6.2
2	0	0	2	8.3	.126	8.7	5.3
0	2	0	2	7.0	.098	9.0	5.6
0	0	2	2	8.7	.124	8.8	6.0
1	1	2	4	8.3	.150	9.5	6.2
2	1	1	4	9.7	.130	8.0	7.9
1	2	1	4	9.3	.124	8.5	6.2
1	3	0	4	8.3	.107	7.3	6.6
0	1	3	4	8.0	.115	7.7	6.2
0	3	1	4	8.0	.114	8.0	7.2
1	0	3	4	7.3	.112	9.2	6.2
3	1	0	4	7.7	.098	7.0	7.7
3	0	1	4	9.0	.110	7.6	7.7
2	2	0	4	7.7	.088	7.3	7.6
0	2	2	4	9.3	.149	8.6	6.1
2	0	2	4	9.0	.114	8.1	6.6
4	0	0	4	7.7	.103	7.9	7.8
0	4	0	4	8.7	.115	7.2	7.2
0	0	4	4	6.7	.071	7.4	6.2

Carbonates.

Sodium.	Potassium.	Ammonium.	Total salts.	Number of plants up.	Weight of dry matter produced.	Height.	Days to come up.
					Gm.	*In.*	
0	0	0	0	8.6	0.116	8.6	6.0
1	0	0	1	8.3	.689	8.6	5.9
0	1	0	1	7.7	.095	6.9	6.5
0	0	1	1	5.3	.084	9.1	5.3
1	½	½	2	8.3	.128	8.3	6.5
½	1	½	2	5.0	.095	11.1	5.3
½	½	1	2	6.3	.092	9.0	5.7
1	1	0	2	8.0	.113	7.6	6.6
0	1	1	2	6.3	.101	10.2	5.1
1	0	1	2	6.0	.081	8.4	6.4
2	0	0	2	9.7	.112	7.1	6.6
0	2	0	2	8.3	.099	6.9	7.4
0	0	2	2	5.7	.092	8.9	6.0
1	1	2	4	6.7	.096	8.9	5.6
2	1	1	4	5.7	.073	8.2	6.2
1	2	1	4	5.7	.088	9.1	5.2
1	3	0	4	5.0	.084	9.0	5.7
0	1	3	4	6.3	.095	9.3	6.6
0	3	1	4	6.0	.098	9.6	5.4
1	0	3	4	6.3	.090	8.7	6.0
3	1	0	4	6.7	.099	7.0	7.6
3	0	1	4	6.7	.113	10.2	5.4
2	2	0	4	6.0	.091	7.4	7.3
0	2	2	4	6.7	.095	8.5	5.8
2	0	2	4	6.0	.092	9.8	5.3
4	0	0	4	6.3	.089	6.7	7.2
0	4	0	4	5.7	.083	8.9	5.2
0	0	4	4	6.3	.066	6.2	6.6

Nitrates.

Sodium.	Potassium.	Magnesium.	Total salts.	Number of plants up.	Weight of dry matter produced.	Height.	Days to come up.
					Gm.	*In.*	
0	0	0	0	8.6	0.116	8.6	6.0
1	0	0	1	8.0	.118	8.3	8.1
0	1	0	1	8.7	.136	7.7	6.6
0	0	1	1	6.7	100	8.8	6.7
1	½	½	2	8.0	.110	8.1	6.9
½	1	½	2	8.7	.130	8.1	7.1
½	½	1	2	8.3	.126	8.4	7.4
1	1	0	2	8.0	.104	7.0	8.1
0	1	1	2	8.3	.113	7.9	7.1
1	0	1	2	8.3	.133	8.1	8.2
2	0	0	2	9.0	.108	6.7	9.7
0	2	0	2	8.0	.096	5.5	8.0
0	0	2	2	8.7	.136	9.2	7.2
1	1	2	4	8.7	.093	5.3	10.5
2	1	1	4	7.0	.063	4.1	13.1
1	2	1	4	7.0	.095	5.4	10.9
1	3	0	4	7.0	.066	2.8	11.8
0	1	3	4	8.3	.104	5.7	9.8
0	3	1	4	7.0	.071	3.2	11.5
1	0	3	4	6.7	.079	5.5	11.4
3	1	0	4	7.0	.044	3.1	13.2
3	0	1	4	6.0	.057	3.9	14.1
2	2	0	4	4.0	.032	3.7	11.3
0	2	2	4	8.3	.099	5.2	10.8
2	0	2	4	6.3	.066	4.5	11.7
4	0	0	4	5.3	.051	3.7	13.5
0	4	0	4	6.7	.052	2.0	12.8
0	0	4	4	8.0	.093	5.3	10.8

Chlorids.

Calcium.	Potassium.	Magnesium.	Total salts.	Number of plants up.	Weight of dry matter produced.	Height.	Days to come up.
					Gm.	*In.*	
0	0	0	0	8.6	0.110	8.6	6.0
1	0	0	1	8.3	.106	6.8	8.9
0	1	0	1	8.7	.140	9.2	6.7
0	0	1	1	8.3	.111	7.5	8.6
1	½	½	2	7.0	.100	8.3	9.3
½	1	½	2	8.3	.121	8.0	9.3
½	½	1	2	6.0	.072	7.0	9.5
1	1	0	2	8.0	.106	7.8	9.8
0	1	1	2	8.0	.125	8.8	9.1
1	0	1	2	7.3	.087	7.4	8.8
2	0	0	2	7.0	.083	7.0	9.3
0	2	0	2	9.0	.135	7.8	8.5
0	0	2	2	7.3	.100	8.2	9.3
1	1	2	4	6.0	.063	4.9	13.7
2	1	1	4	5.7	.048	3.6	14.7
1	2	1	4	4.0	.029	3.4	14.8
1	3	0	4	6.0	.033	2.7	14.2
0	1	3	4	7.0	.063	4.1	13.8
0	3	1	4	4.7	.032	3.8	14.7
1	0	3	4	4.7	.046	4.3	13.4
3	1	0	4	5.7	.030	2.2	13.0
3	0	1	4	5.3	.039	2.9	13.2
2	2	0	4	5.0	.030	3.7	14.8
0	2	2	4	6.0	.058	5.1	14.3
2	0	2	4	6.0	.057	4.5	13.0
4	0	0	4	5.7	.033	3.1	13.2
0	4	0	4	6.3	.064	5.3	14.1
0	0	4	4	6.3	.056	4.9	13.0

Sodium salts.

Sulphate.	Carbonate.	Chlorid.	Total salts.	Number of plants up.	Weight of dry matter produced.	Height.	Days to come up.
					Gm.	*In.*	
0	0	0	0	8.6	0.116	8.6	6.0
1	0	0	1	7.7	.092	5.9	7.2
0	1	0	1	9.0	.112	8.0	5.6
0	0	1	1	7.7	.080	6.5	9.5
1	½	½	2	9.7	.123	6.4	6.0
½	1	½	2	9.3	.128	8.3	5.9
½	½	1	2	9.0	.114	8.1	7.5
1	1	0	2	9.0	.115	6.1	5.6
0	1	1	2	9.7	.111	7.1	8.8
0	1	0	2	8.7	.114	6.1	7.6
2	0	0	2	8.7	.113	5.7	8.9
0	2	0	2	8.3	.103	7.0	6.7
0	0	2	2	7.0	.066	4.4	11.5
1	1	2	4	5.7	.050	3.8	11.9
2	1	1	4	7.7	.095	4.6	11.1
1	2	1	4	6.3	.091	5.2	10.4
1	3	0	4	5.3	.068	3.9	9.5
0	1	3	4	1.3	.008	2.7	14.0
0	3	1	4	7.0	.089	5.7	11.6
1	0	3	4	5.3	.027	2.6	14.0
3	1	0	4	8.3	.107	4.8	9.1
3	0	1	4	7.7	.061	3.6	12.4
2	2	0	4	7.7	.091	3.7	8.0
0	2	2	4	6.0	.051	5.1	14.0
2	0	2	4	4.7	.034	2.2	13.7
4	0	0	4	9.3	.119	5.1	8.0
0	4	0	4	6.3	.081	6.0	7.8
0	0	4	4	1.7	.009	3.0	14.0

3	1½	1½	6	6.3	.066	6.3	8.3	3	1½	1½	6	6.3	.088	8.3	8.3	3	1½	1½	6	3.0	.020	2.4	18.0	3	1½	1½	6	2.0	.011	2.8	16.5	3	1½	1½	6	2.7	.024	3.8	13.5
1½	3	1½	6	5.3	.070	9.0	5.3	1½	3	1½	6	6.7	.088	8.1	5.7	1½	3	1½	6	3.3	.023	2.4	14.2	1½	3	1½	6	1.0	.004	2.3	15.7	1½	3	1½	6	5.3	.040	4.6	13.3
1½	1½	3	6	7.3	.101	7.4	7.0	1½	1½	3	6	6.3	.072	6.6	8.8	1½	1½	3	6	2.3	.011	1.8	14.0	1½	1½	3	6	.7	.003	2.0	19.0	1½	1½	3	6	4.0	.026	3.8	13.6
3	3	0	6	5.7	.093	8.8	6.8	3	3	0	6	5.0	.069	8.0	7.0	3	3	0	6	2.0	.010	1.8	12.8	3	3	0	6	2.0	.007	1.7	16.5	3	3	0	6	8.3	.107	4.8	9.1
3	0	3	6	6.0	.083	7.8	5.3	0	3	3	6	6.3	.075	6.6	7.6	0	3	3	6	3.3	.026	2.2	13.7	0	3	3	6	1.7	.007	2.0	15.7	0	3	3	6	4.0	.026	3.8	13.6
6	0	0	6	7.3	.081	6.9	7.7	3	0	3	6	5.7	.064	6.1	8.4	3	0	3	6	2.7	.018	3.1	12.0	3	0	3	6	2.3	.009	1.9	16.0	3	0	3	6	1.7	.008	1.1	12.8
0	6	0	6	5.7	.078	6.5	8.8	6	0	0	6	5.0	.051	7.2	6.2	6	0	0	6	1.3	.002	2.0	18.0	6	0	0	6	.7	.003	2.0	25.0	6	0	0	6	7.3	.082	5.2	7.1
0	0	6	6	6.3	.107	6.1	7.3	0	6	0	6	6.3	.090	8.5	5.5	0	6	0	6	.3	.002	2.0	12.0	0	6	0	6	1.3	.008	2.7	15.2	0	6	0	6	6.3	.072	7.7	7.0
....	....	....	....	9.3	.109	6.7	6.9	0	0	6	6	3.3	.029	4.5	11.0	0	0	6	6	3.3	.017	2.5	12.8	0	0	6	6	3.0	.014	2.6	15.8	0	0	6	6	0	0	0	0
4	2	2	8	4.7	.069	8.8	6.2	4	2	2	8	6.0	.059	6.3	9.1	4	2	2	8	0	0	0	0	4	2	2	8	0	0	0	0	4	2	2	8	4.3	.030	2.5	13.5
2	4	2	8	5.3	.074	8.4	6.8	2	4	2	8	5.3	.077	7.5	9.0	2	4	2	8	.7	.001	1.0	18.0	2	4	2	8	0	0	0	0	2	4	2	8	4.3	.032	3.0	13.6
2	2	4	8	5.3	.091	9.4	5.7	2	2	4	8	2.7	.031	4.7	13.2	2	2	4	8	2.0	.009	2.2	12.0	2	2	4	8	1.3	.002	1.0	20.0	2	2	4	8	0	0	0	0
2	6	0	8	4.0	.054	8.0	8.0	2	6	0	8	6.3	.090	9.3	6.5	2	6	0	8	1.3	.004	1.0	12.0	2	6	0	8	0	0	0	0	2	6	0	8	6.0	.080	5.2	9.0
0	2	6	8	7.0	.104	7.0	8.7	0	2	6	8	2.7	.029	4.9	12.4	0	2	6	8	2.0	.015	2.4	18.0	0	2	6	8	.7	.002	1.0	18.0	0	2	6	8	0	0	0	0
0	6	2	8	5.7	.088	9.1	5.6	0	6	2	8	4.7	.069	8.0	14.5	0	6	2	8	.3	.002	2.0	12.0	0	6	2	8	0	0	0	0	0	6	2	8	5.3	.041	4.6	13.5
6	2	0	8	5.3	.079	9.2	8.4	6	2	0	8	5.7	.065	8.0	5.2	6	2	0	8	.7	.002	1.0	12.0	6	2	0	8	.3	.000	1.0	25.0	6	2	0	8	6.0	.062	3.0	12.2
6	0	2	8	6.0	.094	8.3	8.9	6	0	2	8	6.3	.060	5.6	10.3	6	0	2	8	.3	.001	1.0	12.0	6	0	2	8	0	0	0	0	6	0	2	8	4.0	.043	2.4	12.8
2	0	6	8	6.0	.102	6.9	9.4	2	0	6	8	1.0	.005	2.7	16.0	2	0	6	8	1.7	.006	1.1	18.0	2	0	6	8	0	0	0	0	2	0	6	8	.7	.002	1.0	14.0
4	4	0	8	4.3	.058	8.4	8.4	4	4	0	8	5.7	.079	9.1	5.6	4	4	0	8	.0	0	0	0	4	4	0	8	0	0	0	0	4	4	0	8	6.7	.075	5.1	10.2
0	4	4	8	6.3	.095	6.7	9.2	0	4	4	8	3.7	.039	3.7	15.1	0	4	4	8	.7	.001	1.0	12.0	0	4	4	8	.7	.002	1.0	18.0	0	4	4	8	.7	.003	1.5	13.5
4	0	4	8	6.3	.086	6.4	9.4	4	0	4	8	5.0	.038	5.7	11.9	4	0	4	8	2.0	.008	2.5	18.0	4	0	4	8	.3	.000	1.0	25.0	4	0	4	8	3.0	.011	1.0	13.5
8	0	0	8	6.0	.075	7.8	10.0	8	0	0	8	6.0	.062	7.1	6.5	8	0	0	8	.0	0	0	0	8	0	0	8	0	0	0	0	8	0	0	8	6.3	.073	5.8	12.4
0	8	0	8	6.3	.103	9.2	6.0	0	8	0	8	6.3	.084	7.7	5.5	0	8	0	8	1.3	.004	1.0	12.0	0	8	0	8	0	0	0	0	0	8	0	8	5.7	.058	6.5	7.6
0	0	8	8	7.3	.108	6.9	8.4	0	0	8	8	1.0	.004	1.7	14.3	0	0	8	8	2.0	.009	2.3	12.0	0	0	8	8	1.3	.005	2.5	25.0	0	0	8	8	0	0	0	0
5	2½	2½	10	5.3	.066	8.1	8.2	5	2½	2½	10	4.3	.047	6.4	14.1	5	2½	2½	10	0	0	0	0	5	2½	2½	10	0	0	0	0	5	2½	2½	10	2.7	.012	2.0	13.5
2½	5	2½	10	5.7	.068	8.5	6.6	2½	5	2½	10	3.3	.036	5.0	12.8	2½	5	2½	10	0	0	0	0	2½	5	2½	10	0	0	0	0	2½	5	2½	10	3.7	.012	1.7	13.5
2½	2½	5	10	5.7	.100	10.1	7.7	2½	2½	5	10	0	0	0	0	2½	2½	5	10	.7	.001	1.0	12.0	2½	2½	5	10	0	0	0	0	2½	2½	5	10	0	0	0	0
5	5	0	10	5.3	.079	8.2	7.8	5	5	0	10	6.3	.086	8.0	7.0	5	5	0	10	0	0	0	0	5	5	0	10	0	0	0	0	5	5	0	10	5.7	.056	4.0	13.5
0	5	0	10	4.7	.055	6.1	9.4	0	5	5	10	0	0	0	0	0	5	5	10	.7	.001	1.0	12.0	0	5	5	10	0	0	0	0	0	5	5	10	0	0	0	0
5	0	5	10	5.7	.076	8.5	7.1	5	0	5	10	.7	.004	2.5	11.0	5	0	5	10	0	0	0	0	5	0	5	10	0	0	0	0	5	0	5	10	0	0	0	0
10	0	0	10	6.0	.079	7.7	10.9	10	0	0	10	5.3	.042	5.0	9.6	10	0	0	10	0	0	0	0	10	0	0	10	0	0	0	0	10	0	0	10	5.0	.038	5.0	13.5
0	10	0	10	6.0	.069	7.1	8.2	0	10	0	10	6.3	.074	5.4	8.1	0	10	0	10	0	0	0	0	0	10	0	10	0	0	0	0	0	10	0	10	3.7	.032	3.9	10.1
0	0	10	10	4.0	.064	9.5	5.4	0	0	10	10	0	0	0	0	0	0	10	10	1.7	.010	2.4	12.0	0	0	10	10	0	0	0	0	0	0	10	10	0	0	0	0

The top line in each case gives the results where no salts were applied. Below this the figures are arranged according to the total quantity of salt used, first 1,000 p. p. m., followed by 2,000, 4,000, 6,000, 8,000, and 10,000. It will be noted that with the chlorids and nitrates practically no plants grew in the higher concentrations. Careful study of the table is necessary to see the numerous complex relations that are brought out between the various salts. The simple relations may be seen more easily in figures 2 to 24, but by bringing together a large mass of data in one table many relations can be found that could not be seen in the diagrams.

The average alkali of Utah contains a mixture of chlorids, sulphates, and carbonates, with the carbonates usually present only in small quantities. The practical alkali problem, therefore, is largely centered around the sulphates and chlorids of sodium. An examination of Table XVI does not seem to indicate that either of these salts has any great neutralizing effect on the other.

A general conclusion from this table might be that where alkali salts are found together in the soil the toxic action of the combined salts is only slightly less than the sum of the toxicities of the individual salts. It may be that with other combinations of salts this conclusion would not be justified.

PRACTICAL LIMITS OF THIS PROBLEM

The practical problem of this entire study is to determine the quantity of various alkali salts necessary in the soil to reduce the growth of crops beyond the point of profitable production. Under the conditions of dry farming there is no practicable way of removing excessive soluble salts; hence, if salts are found in these soils in quantities prohibiting crop growth, the soils are valueless for agriculture. On the other hand, soils that are susceptible of irrigation and drainage may be reclaimed by the leaching out of the alkali. In any soil, however, where there is a likelihood of alkali injury it is very important, in order to be able to judge the value of a soil, to know exactly how much of a given salt is necessary to injure crops. The literature on the subject up to the present is somewhat conflicting and lacks the definiteness that would be desirable.

There are so many factors entering into the toxicity of alkali that it is difficult to assign definite toxic limits. For example, an analysis might show a soil to contain a given percentage of salt when in reality the greater part of the salt might be in a crystallized form at the surface, where it would do no harm until dissolved and washed back into the soil. It is the salt in solution that does the real injury. The wetness of the soil, its texture, the presence of neutralizing substances, and a number of other factors all alter the toxicity of soluble salts, which

makes it impossible to say exactly what are the practical limits of alkalies.

In getting the limits given below it was considered that when alkali retarded germination and growth to about half what they were in soils without alkali the practical limit had been reached. Certainly it would not be profitable to use a soil where alkali decreased yields below half normal.

Figures 46 and 47 show the practical limits of growth of wheat in loam and sand for 13 different salts. It will be noted that these salts bear a similar relation to each other in both kinds of soil, although only about half as much alkali is required in sand to reach the toxic limit as in loam. One of the most striking features about the diagram is the fact that in sand the carbonates are proportionately more toxic when compared with other salts than they are in loam.

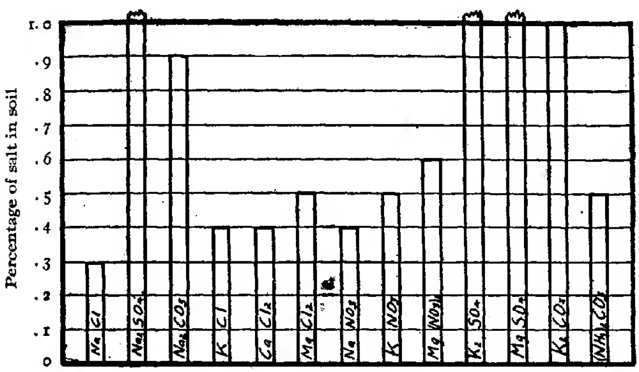


FIG. 46.—Diagram showing the percentage of alkali salt in loam soil giving about half normal germination and production of dry matter in wheat.

Loam having 0.3 per cent and sand having 0.2 per cent of sodium chlorid contain a limit of this salt for the profitable production of crops. The other chlorids may be somewhat higher, while the nitrates may be about 0.1 per cent higher than the chlorids. On loam crops grow well with as high as 1 per cent of the sulphates, while in sand from 0.5 to 0.7 per cent of the sulphates is injurious.

Figure 48 gives a comparison of the resistance of barley, oats, wheat, alfalfa, sugar beets, corn, and Canada field peas for sodium chlorid, sodium carbonate, and sodium sulphate in loam. Barley can withstand 0.5 per cent of sodium chlorid, 1 per cent of sodium carbonate, and more than 1 per cent of sodium sulphate. All crops in the test except oats, sugar beets, corn, and field peas produced more than half normal growth where 1 per cent of sodium sulphate was present. There was a great difference in the resistance of various crops to sodium carbonate, the

practical limit ranging from 0.4 per cent for Canada field peas up to 1 per cent for barley. Sodium chlorid showed about the same toxicity for all the crops except barley and oats, which were slightly more resistant. The striking point about this diagram is the fact that the relative toxicity of the different salts varies for each crop.

SUMMARY

(1) The effect of the various alkali salts in soils on plant growth and the quantity of alkali that must be present to injure crops are of great practical importance to farmers in arid regions, as well as of considerable interest to the scientist.

(2) A great amount of work has already been done on alkali, but this does not give all the information that is needed.

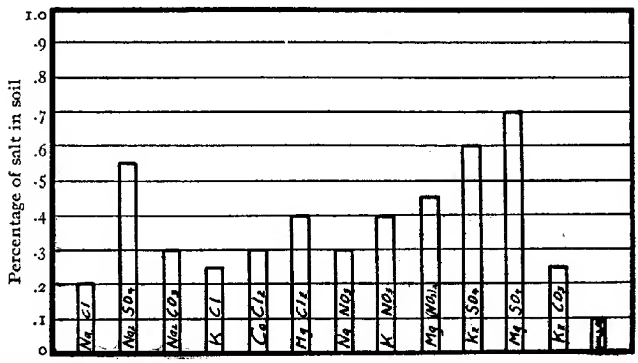


FIG. 47.—Diagram showing the percentage of alkali salt in coarse sand giving about half normal germination and production of dry matter in wheat.

(3) In this paper results of over 18,000 determinations of the effect of alkali salts on plant growth are reported.

(4) Only about half as much alkali is required to prohibit the growth of crops in sand as in loam.

(5) Crops vary greatly in their relative resistance to alkali salts, but for the ordinary mixture of salts the following crops in the seedling stage would probably come in the order given, barley being the most resistant: Barley, oats, wheat, alfalfa, sugar beets, corn, and Canada field peas.

(6) Results obtained in solution cultures for the toxicity of alkali salts do not always hold when these salts are applied to the soil.

(7) The percentage of germination of seeds, the quantity of dry matter produced, the height of plants, and the number of leaves per plant are all affected by alkali salts in about the same ratio.

(8) The period of germination of seeds is considerably lengthened by the presence of soluble salts in the soil.

(9) The anion, or acid radical, and not the cation, or basic radical, determines the toxicity of alkali salts in the soil. Of the acid radicals used, chlorid was decidedly the most toxic, while sodium was the most toxic base.

(10) The injurious action of alkali salts is not in all cases proportional to the osmotic pressure of the salts.

(11) The toxicity of soluble salts in the soil was found to be in the following order: Sodium chlorid, calcium chlorid, potassium chlorid, sodium nitrate, magnesium chlorid, potassium nitrate, magnesium nitrate,

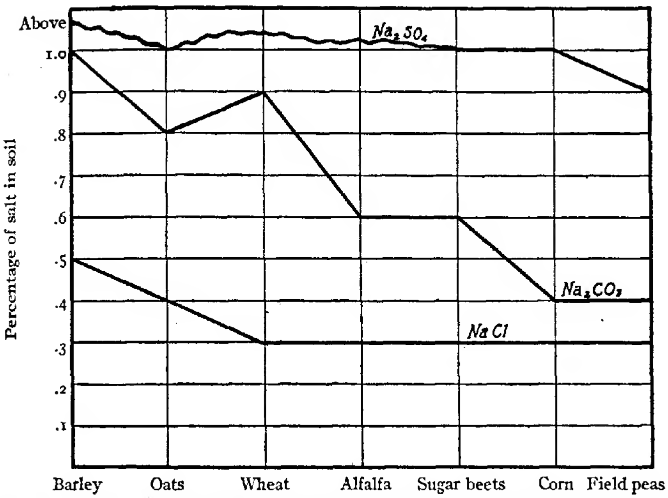


FIG. 48.—Curve showing the percentage of sodium chlorid, sodium carbonate, and sodium sulphate in Greenville loam giving about half normal germination and production of dry matter.

sodium carbonate, potassium carbonate, sodium sulphate, potassium sulphate, and magnesium sulphate.

(12) The antagonistic effect of combined salts was not so great in soils as in solution cultures.

(13) The percentage of soil moisture influences the toxicity of alkali salts.

(14) Salts added to the soil in the dry state do not have so great an effect as those added in solution.

(15) Land containing more than about the following percentages of soluble salt are probably not suited without reclamation to produce ordinary crops. In loam, chlorids, 0.3 per cent; nitrates, 0.4 per cent; carbonates, 0.5 per cent; sulphates, above 1.0 per cent. In coarse sand, chlorids, 0.2 per cent; nitrates, 0.3 per cent; carbonates, 0.3 per cent; and sulphates, 0.6 per cent.

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HISTOLOGICAL RELATIONS OF SUGAR-BEET SEEDLINGS AND PHOMA BETAE

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In a former paper[2] it was pointed out that practically all sugar-beet (*Beta vulgaris*) seed is more or less heavily infected with *Phoma betae* (Oud.) Fr., and that a large proportion of the seedlings developing from such stock suffer from incipient or severe attack of the fungus, but that under favorable conditions a high percentage of the attacked plants recover sufficiently to make a good growth. It appears that the period during which the sugar beet is susceptible to infection by this fungus is confined to the seedling stage, or, in the case of leaves, to old age, but that when infection has once occurred, it persists. After apparent recovery of the host, the fungus is still present, although it remains concealed until conditions arise sufficiently unfavorable to the beet to enable the parasite to renew its attack. Except in the seedling stage, it seldom accomplishes the immediate destruction of its host, but remains inactive during the first growing season and becomes destructive on mother beets in storage or reappears during the second growing season on the seed stalks or racemes in time to cause infection of the new crop of seed.

Histological studies recently conducted upon seedling sugar beets infected with *Phoma betae* have shown the fungus fruiting on the surface of young plants that were scarcely past the cotyledon stage. They have also revealed the organism living without serious injury to the host, within the deeper cells of plants that had thrown off the attack and which could safely be predicted to show no further sign of infection during the growing season if reasonably good cultural conditions were maintained. The slides show that the fungus may persist both in and on the tissues of the beet and also indicate something of its *modus operandi* in attack on seedlings. Sections were prepared from material grown from pasteurized seed in experimental pots in sterilized soil which had been inoculated at the time of seeding with pure cultures of the fungus. The material was controlled by check pots and by recovery of the fungus from certain of the seedlings from each pot as the disease appeared. Damped-off and root-sick seedlings selected at different stages in the progress of the disease and healthy

[1] The author wishes to acknowledge his indebtedness to Mrs. Nellie D. Morey, formerly of the Office of Cotton and Truck Disease Investigations, for assistance in the preparation of slides.

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Journal of Agricultural Research, Dept. of Agriculture, Washington, D. C
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Vol. V, No. 1
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seedlings from the control pots were killed in Flemming's solution, embedded, sectioned, and stained with the triple combination in the usual way. Camera-lucida drawings from the slides thus prepared are employed to illustrate this discussion. Most of the seedlings were still in the cotyledon stage, but some that had recovered from the attack had developed their first pairs of leaves. Seedlings which had been entirely killed were so badly disintegrated or so softened by the disease that they did not yield satisfactory material for study. The sections showed the cells in a condition of complete collapse and decay. The cellulose layers of the walls, as well as the middle lamella, were gelatinized and softened to such an extent as to have lost most of their rigidity. The walls were broken and fragmented, but this may have resulted from handling during the process of washing and dehydrating. Bacteria were present, of course, and the softening of the walls, which made them so liable to fracture in handling, may have been due in part to the action of these agents.

Cells of badly diseased but still living seedlings presented more favorable material for studying the histological relations of the parasite and host. The cells were often nearly filled with the fungus, which showed a tendency to remain within the cell rather than in the middle lamella, although it frequently penetrated the walls (Pl. I, fig. 1). Now and then a thread of the fungus was observed running between the cells for a little distance, but the indications are that, while the organism dissolves the middle lamella, it does not feed upon it. Heavily invaded cells are consumed, the cytoplasm disappears, and the nuclei disintegrate. The middle lamella gelatinizes, so that the cellulose lamellæ may become widely separated while the cellulose layers are broken and disintegrated or even dissolved (Pl. I, fig. 2). The first visible indication of the alteration in the walls is a change in their reaction toward the stain. They take the safranine more deeply and retain it more tenaciously than do the walls of normal cells. With the progress of the disease a border area of increasing width, which also takes the safranine deeply, develops on either side of the walls, as if the substances which retained the dye were gradually diffusing from the wall and spreading into the surrounding space.

In cases of less serious infection, where recovery is possible, or in tissues which have just been invaded, a somewhat different condition exists. Plate I, figure 3, represents a recently invaded portion of a rather badly diseased seedling which would probably have been unable to recover. The cell walls show the gelatinized condition only in a moderate degree and in an area confined to the points where it has been penetrated by the mycelium. The mycelium has expanded in one of the cells in a manner not frequently noted, and the effect of the parasitism is apparent in the abnormal condition of the host nuclei. Evidence of disease was sometimes manifested in the neighboring uninfected cells of such mate-

rial by the unusual appearance of the nuclei. Dumb-bell forms, budding, and indirect division were observed occasionally, but never in any large number (Pl. I, fig. 4, 5, 6).

The most interesting phenomena in many respects, as well as the most puzzling, are those associated with recovery and healing. Sugar beets attacked by the fungus frequently send out new side roots from a point above the invasion and succeed in preventing the destruction of this new growth. Cases were common in which the region invaded and disintegrated had been confined to the outer tissue. The central vascular region and the surrounding layers of cells resisted the attack and eventually succeeded in sloughing off the killed tissue. The fungus was frequently found developing its pycnidia on the killed portions of such recovering seedlings, while the host tissue, only a few cells below, appeared perfectly normal (Pl. II, fig. 1).

The most striking thing brought out by a study of the sections, however, is the presence of the fungus apparently established in a condition of reduced relative virulence in the interior tissue of beets which have recovered from the attack and which are assured of making a good growth (Pl. II, fig. 2). In such cases even the invaded cells are not killed, and the adjacent ones appear perfectly normal in every respect. So far as has been observed, the cells thus invaded are adjacent to vascular tissue, but the organism has never been seen in the conducting elements. The infection is confined to a vertical chain of cells, and in no case was more than a single unbranched hypha observed.

The physiological relation here presented is an exceedingly interesting one and its investigation is of the highest scientific and practical importance.

It is difficult to explain just how an organism capable of producing such complete collapse in cells of seedlings should suddenly find its action checked and confined to a saprophytic existence on an area of discarded surface tissue, but the means by which it establishes itself within the highly nutritive living cells of the interior and is at the same time compelled to remain in a quiescent condition is still more problematical. The condition presents a relatively highly developed type of parasitism in which the organism voluntarily or by compulsion permits the completion of the normal life history of the host while securing for itself the assurance of perpetuation through infection of the seed. The balance, however, is not a perfect one, since, if the host encounters sufficiently adverse conditions during either of the growing seasons or in storage, the activity of the parasite is renewed and the sugar beet is destroyed, thus preventing seed production and the perpetuation of the parasite through the seedling channel.

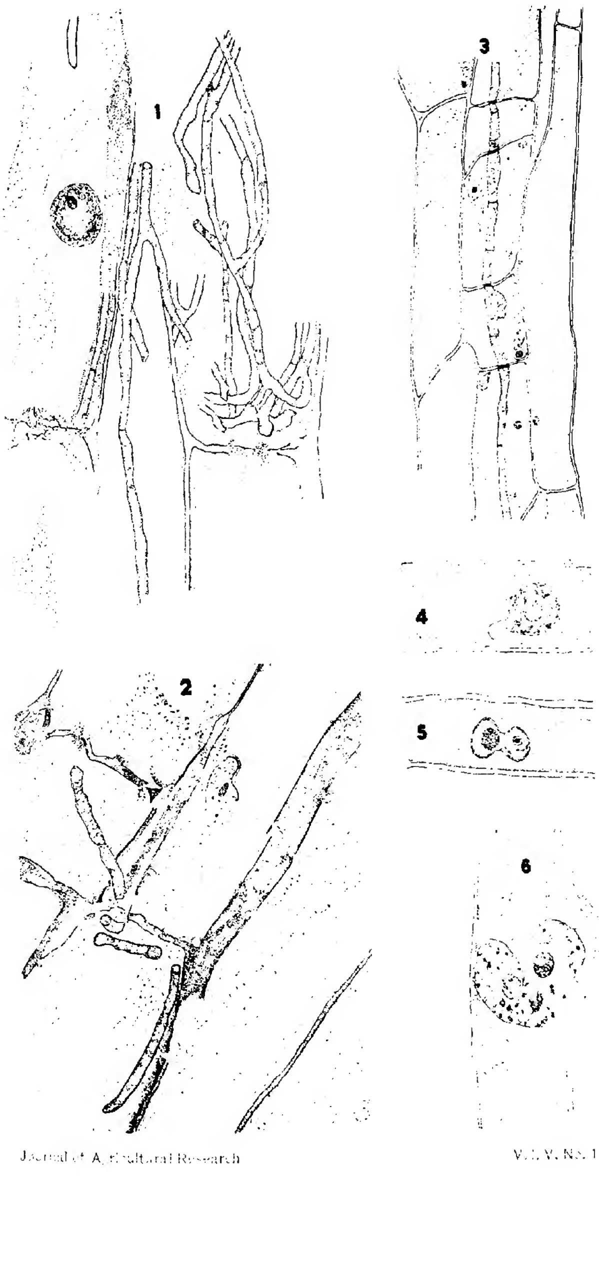
PLATE I

Fig. 1.—Section of a sugar-beet seedling invaded by *Phoma betae*, showing distribution of the mycelium and the action of the fungus on the protoplasm and cell walls. × 530.

Fig. 2.—Section of sugar-beet seedling showing characteristic action of *Phoma betae* on the cytoplasm and nuclei and cell walls in cases of serious infection. Note the gelatinized condition of the middle lamella. × 530.

Fig. 3.—Section of sugar-beet seedling showing *Phoma betae* penetrating the cell walls and expanding in one of the cells. The nuclei show signs of degeneration. × 530.

Fig. 4, 5, and 6.—Abnormal nuclei from uninfected cells adjacent to invaded tissue of sugar-beet seedlings. The nucleus in figure 6 appears to be in the process of direct division. × 1,330.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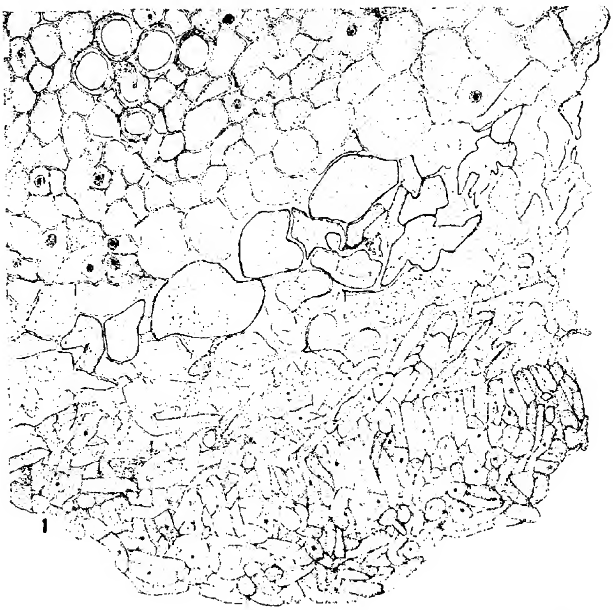

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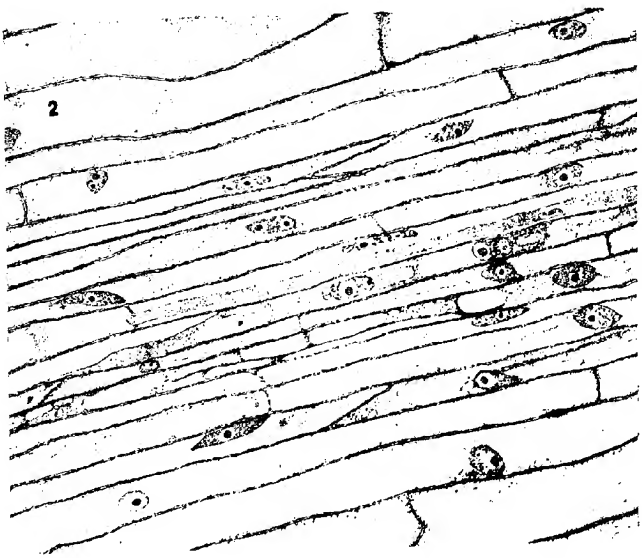

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PLATE II

Fig. 1.—Section through a sugar-beet seedling which has recovered from an attack of *Phoma betae*, showing a young pycnidium of the fungus forming on the discarded, killed tissue. × 500.

Fig. 2.—Longitudinal section through a sugar-beet seedling which had recovered from an attack of root sickness due to *Phoma betae*, showing the presence of the fungus established in a condition of reduced virulence in the living cells. × 530.

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